Texture Distribution of the Younger Alluvial Sediments and Parts of the Tehama Formation in Portions of Yolo, Solano, Colusa, and Sacramento Counties, California

By

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TEXTURE DISTRIBUTION OF THE YOUNGER ALLUVIAL SEDIMENTS AND PARTS OF THE TEHAMA FORMATION IN PORTIONS OF YOLO, SOLANO, COLUSA, AND SACRAMENTO COUNTIES, CALIFORNIA

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ABSTRACT

Three hundred ninety six driller's logs and 809 electric logs were used to identify the contact between the Upper Pliocene Tehama Formation and overlying younger alluvial sediments. The vertical and lateral distribution of alluvial sediment texture is characterized by these well logs in parts of Yolo, Solano, Colusa, and Sacramento Counties, California. The elevation of the top of the Tehama Formation was determined at 257 well locations by using point resistance and spontaneous potential logs, as well as descriptions of the sediments logged by the drillers. Elevation contours of the top of the Tehama Formation show a general eastward to southeastward dip, with structural highs and lows that trend in a northwest direction. In this thesis, two alluvial texture classifications of coarse-grained and fine-grained are used. Coarse-grained sediment consist primarily of sand, clayey or silty sand, clayey, silty or sandy gravel, and gravel. Fine-grained sediment consist primarily of clay, silt, and sandy clay or silt. Alluvial texture information from driller's logs and electric logs

from 396 wells ranging from 60 feet to over 1,200 hundred feet deep, and drilling a total of 155,799 feet, was collected. A comparison of alluvial texture collected from driller's logs to electric logs shows that the driller's logs underestimate the amount of coarse-grained sediment by 10,000 feet, overestimate the amount of fine-grained material by over 3,000 feet, and contain approximately 2.5 times the amount of missing or ambiguous material. Electric logs provide more accurate alluvial texture information, and are used to generate maps that show the distribution of coarse-grained alluvium with depth. The younger alluvial sediments range in thickness from less than 5 feet to nearly 180 feet, and consist of a heterogeneous mixture of materials that vary greatly in composition over short distances. Coarse-grained materials comprise nearly one-half the total volume within the younger alluvial sediments, and reach a maximum of 76% in the 150 to 175-foot depth range. The upper 400 feet of the Tehama Formation consists of 27% coarse-grained sediment and 73% fine-grained sediment which were probably deposited under flood-plain conditions. Below 100 feet beneath the top of the Tehama Formation, the sediments become finer with depth, and are finest in the 200 to 250-foot depth interval, where the fine-grained sediments make up nearly 76% of the materials.

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INTRODUCTION

PURPOSE AND SCOPE

The purpose of this thesis is to locate the contact between the Tehama Fomation and the overlying younger alluvial sediments, and to describe the alluvial texture distribution of the overlying younger alluvial sediments and the upper 400 feet of the Tehama Formation in parts of Yolo, Solano, Colusa, and Sacramento Counties, California. Driller's logs, point resistance logs, and spontaneous potential logs were used to determlne the contact between the Upper Pliocene Tehama Formation and the overlying younger alluvial sediments, and to characterize the vertical and lateral distribution of coarse- and fine-grained alluvial sediments. Locating the contact between the Tehama Formation and the overlying younger alluvial sediments is important because of the probable differences in the relationship between alluvial sediment texture and aquifer parameters in the unconsollidated younger alluvial sediments as compared to the semiconsollidated sediments of the Tehama Formation, and also because of disagreements in the location of the top of the Tehama Formation. In the past, the texture distribution of the fresh ground water-bearing sediments in the Central Valley has been described generally by the use of driller's logs. A secondary objective of this thesis is to quantitatively evaluate driller's logs as a source of alluvial texture data.

This study is a component of a larger study conducted by the U. S. Geological Survey, in cooperation with the California Department of Water Resources, whose purpose is to quantify the hydrologic and geologic characteristics of the ground-water flow system of the Sacramento Valley and theRedding Basin.

The analysis of alluvial texture presented in this thesis will provide a basis for estimation of aquifer parameters and a rationale for adjustment of those parameters during calibration of ground-water flow models. This thesis also contains information on areas of potential land subsidence.

DESCRIPTION OF STUDY AREA

The area of investigation lies within the Sacramento Valley, a northwest-trending, asymmetrical, structural trough extending from Sacramento northward to Redding, that has been filled with as much as 10 vertical miles of sediments ranging in age from Jurassic to Holocene (Page, 1986) (Figure 1). The Sacramento Valley is bordered by pre-Tertiary granitic and metamorphic rocks of the Sierra Nevada on the east, by Miocene and Pliocene volcanic rocks and deposits of the Cascade Range on the northeast, by folded and faulted pre-Tertiary volcanic and metamorphic rocks of the Klamath Mountains to the north, and by folded and faulted pre-Tertiary marine and related continental rocks of the coast ranges on the west . To the south, the valley merges with the San Joaquin Valley, and together they form the Central Valley.

The principal study area is located on the western flank of the Sacramento Valley, extending from Rumsey south to the foothills east of Allendale, and continues eastward to the western edge of the Yolo bypass (Figure 2). The study area, encompassing approximately 1350 square miles, is comprised mainly of flood plains, low-lying alluvial plains, and dissected uplands of relatively low relief.

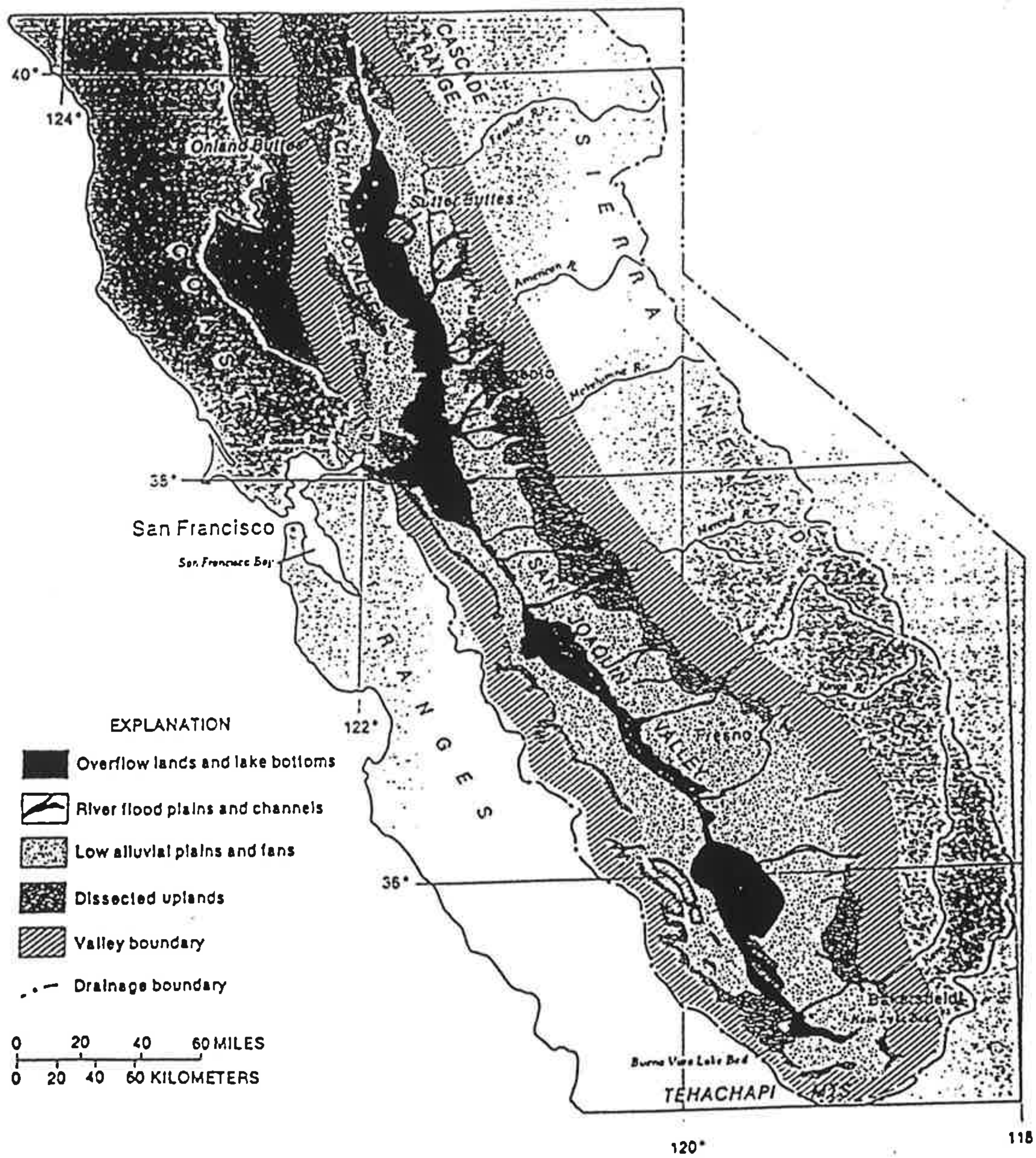

Figure 1. Geomorphic units of California (from Page, 1986).

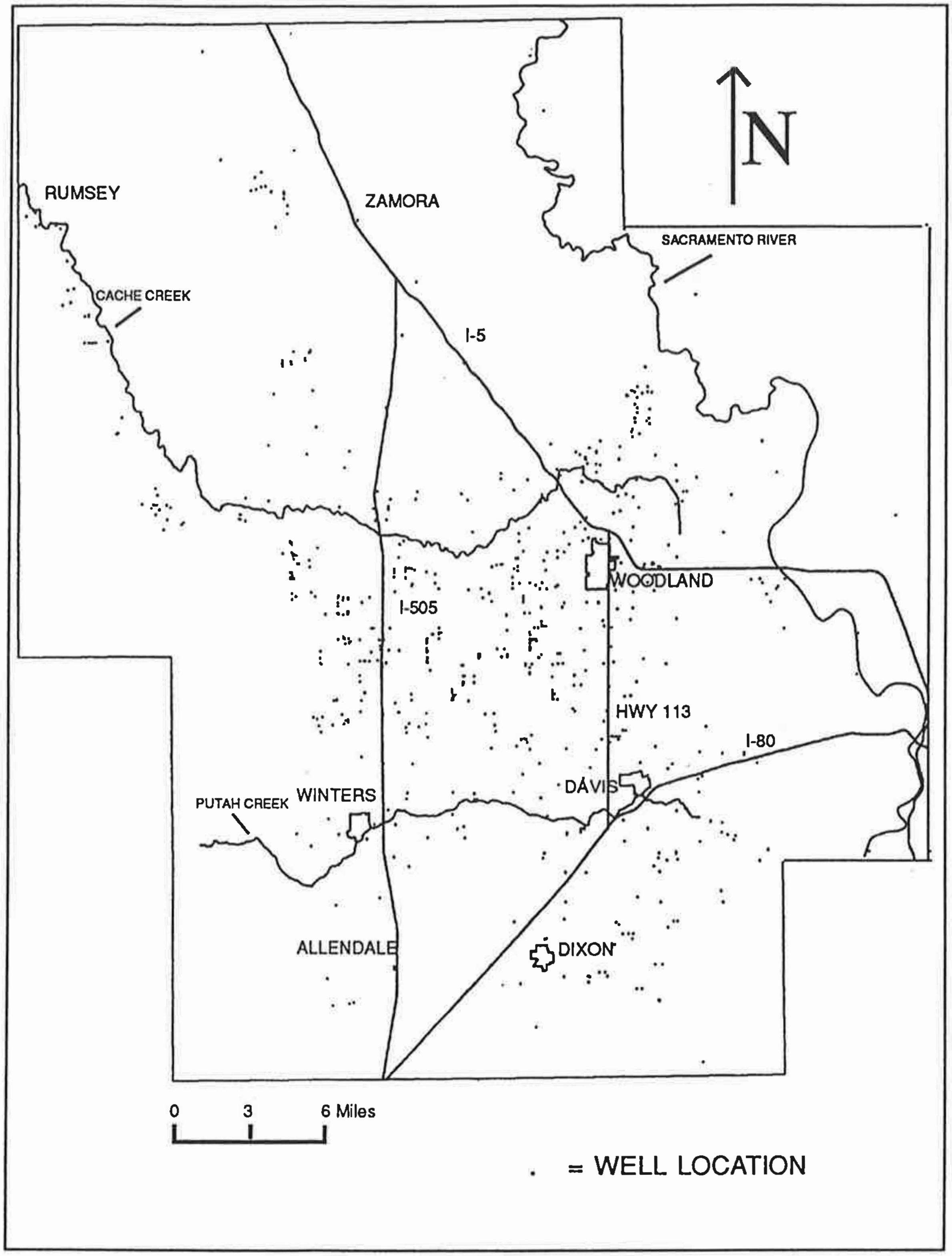

Figure 2. Location of Study Area.

PREVIOUS INVESTIGATIONS

Previous investigations within the study area include Russell and Vanderhoof (1931) who originally named and described the Tehama Formation. Later, Vanderhoof (1933) assigned an age of upper Pliocene or Pleistocene to the Tehama Formation.

Anderson and Russell (1939) described the physical characteristics, distribution, and thickness of the Tehama Formation and overlying rocks of the Red Bluff Formation and younger sediments (Table 1). They found the contact between the Tehama Formation and overlying deposits of the Red Bluff Formation and younger alluvium difficult to distinguish in some areas of the Sacramento Valley, and therefore grouped the Red Bluff Formation and some of the younger alluvial sediments with the Tehama Formation.

Thomasson et al. (1960) described in detail the geology and water bearing characteristics of the Putah Creek area. Their report included a lithologic study of the Tehama Formation and the overlying alluvial and stream channel deposits. Owing to the difficulty of distinguishing the Tehama Formation from the overlying Red Bluff Formation and younger terrace deposits, Thomasson et al. assembled these units into one geologic unit designated as the Tehama Formation. This study utilized electric logs from gas-test wells to decribe the middle and basal sections of the Tehama Formation, and used detailed driller's logs to describe the upper sections of the Tehema Formation and overlying alluvial sediments. Cross-sections showing a profile of the contact between the Tehama formation and overlying younger alluvial deposits were also included in their report.

Olmstead and Davis (1961) described the geology and ground-water

SYSTEM	SERIES	GEOLOGIC UNIT	GENERAL CHARACTERISTICS
QUATERNARY	RECENT	ALLUVIAL, FLOOD-BASIN AND STREAM CHANNEL DEPOSITS	Unconsolidated sands, gravels, and clays along channels, flood plains, and natural levees of Putah and Cache Creeks, and the Sacramento River. Heterogeneous mixture of fluviatile sediments.
	PLEISTOCENE	RED BLUFF FORMATION	Discontinous, poorly sorted sand and gravel, containing variable amounts of silt and clay. unconformably overlying the Tehama Formation.
TERTIARY	PLIOCENE	TEHAMA FORMATION	Mostly consolidated to semi- consolidated silt and clay, with varying amounts of sand and gravel. Fluviatile origin. Derived from the Coast Ranges west of the Sacramento Valley. Unconformably rests on Pre-Tertiary rocks.
PRE-TERTIARY		METAMORPHIC, INTRUSIVE, AND SEDIMENTARY ROCKS	Undivided metamorphosed Paleozoic and Mesozoic volcanic and sedimentary rocks.

TABLE 1. Geologic Units of Study Area (modified from California Department of Water Resources, 1978, and Helley and Harwood,1985).

storage capacity of the sediments filling the Sacramento Valley. Their report included computations of ground-water storage capacity and descriptions of ground-water storage units of the Sacramento Valley. In order to estimate the storage capacity of the water bearing deposits, Olmstead and Davis classified the materials of the subsurface using driller's logs. The Red Bluff Formation , Pliocene and Pleistocene alluvial deposits, and the Tehama Formation were grouped into a single geologic unit. Locations of the contact between the grouped geologic unit and the overlying alluvial sediments was also determined from the driller's logs. Their report included geologic cross-sections of parts of the Sacramento Valley showing the estimated contact between the grouped geologic unit and overlying alluvial sediments.

The California Department of Water Resources, in cooperation with the U. S. Geological Survey (1978), wrote a comprehensive report on the geology, geohydrology, and hydrologic inventory of the Sacramento Valley. In their study, gross hydrologic properties of the water-bearing materials including storage capacities, specific yields, and transmissivities were determined. Other hydrologic conditions of the Sacramento Valley, such as ground-water movement, sources and amounts of recharge and discharge, and long term changes in water levels were studied.

Wahler Associates (1982) conducted a geologic study of the aggregate resources along Cache Creek. Their study was based on the analysis and evaluation of well driller's logs. Their report included 18 geologic cross-sections based on the geologic interpretation of the driller' logs, that included profiles of the contact between the Tehama Formation and the overlying alluvial sediments. The cross-sections were used to estimate the distribution and quantify the extractable aggregates located along Cache

Creek.

Helley and Harwood (1985) mapped the late Cenezoic deposits of the Sacramento Valley. Unlike previous investigators, Helley and Harwood were able to locate and map the contact between the Tehama Formation and the overlying Red Bluff Formation or post Red Bluff alluvial sediments. Helley and Harwood's mapping techniques were based largely on geologic interpretation of aerial photographs and published and unpublished soil-series maps. Some of the mapping was incorporated directly from published sources, or was modified from published or unpublished sources.

Page (1986) analyzed the porportion of coarse-grained to fine-grained sediments of the Central Valley. Using 685 geophysical logs obtained mostly from oil and gas wells, texture maps of the sediments beneath the Central Valley were made by computing and plotting the percentage of coarse-grained sediment by quarter townships in depth intervals of 300 feet. Included in his report were texture columns and graphs of the frequency of occurrence of coarse-garined sediment by depth zones for the Sacramento Valley. Most of the textural infomation included in his report was for depths below 300 feet. This was because the oil and gas wells were cased from the ground surface to ten percent of the well depth, blocking the recording of resistivity and spontaneous potential.

Harwood and Helley (1987) mapped the major late Cenezoic structural features and depth to the basement of the Sacramento Valley, in their investigation of the late Cenozoic tectonism of the Sacramento Valley. Their report included analysis of structural features located within the study area of this thesis.

The State of California (1987) studied the structural features and geology of parts of Yolo and Solano Counties, in their site proposal report for the superconducting super collider. Their report included an analysis of 1700 well driller's logs used to determine lithologic information and the location of the contact between the Tehama Formation and overlying alluvial deposits. Typically, their location of the top of the Tehama Formation was identified on the basis of the slightly drier, more compact character, and more yellow color of the Tehama Formation, and the presence of gravel above the contact. Poorly sorted reddish gravels overlying yellow clays were also used as an indicator of the contact, and were correlated to similiar logs without color designations. Their report included a geologic profile of the proposed site showing a smoothed profile of the contact between the Tehama Formation and overlying Quaternary deposits.

This thesis is divided into five sections. The first section, entitled "Geological Features", discusses the geology and structural features of the area under investigation. The second section entitled "Elevation of the Top of the Tehama Formation" discusses methods used to determine the contact between the Tehama Formation and the overlying younger alluvial sediments, and the results of this analysis. The third section entitled "Comparison of Driller's Logs and Electric Logs as A Source of Alluvial Texture Information", describes the methods used in compiling these two independent data bases and the comparison of texture data derived from each. The fourth section, entitled "Texture Distribution of Alluvial Sediments", describes the textural distribution of the recent alluvium and parts of the Tehama formation to a depth of approximately 500 feet below land surface. The final section, entitled "Summary and Conclusions", summarizes the major findings of this thesis.

GEOLOGICAL FEATURES

GEOLOGY

The area under investigation is underlain at depth by pre-Tertiary alluvial and marine clastic sedimentary rocks. These rocks, which crop out on the western border of the study area, generally range from low in permeability to nearly impermeable, and contain connate or dilute-connate saline water (Olmstead and Davis, 1961)(Plate 1). Overlying these marine sediments and croping out in thick sections from west of Winters and north to Esparto are the clays, silts, sands, and gravels of the Pliocene Tehama Formation. Harwood and Helley (1985) also mapped scattered Tehama outcrops from the Dunnigan Hills south towards Dixon. The Tehama Formation dips generally less than 5 degrees in an eastward direction towards the axis of the Sacramento Valley where it interfingers with the Pliocene volcanic rocks and associated arkosic sediments of the Laguna Formation (Olmstead and Davis,1961). The maximum thickness of the Tehama Formation is more than 2,000 feet in parts of Glenn and Tehema Counties (Anderson and Russell, 1939), although it appears to be no more than 1200 feet thick in the study area near Winters (Olmstead and Davis,1961). Anderson and Russell (1931) concluded that the sediments belonging to the Tehama Formation were probably deposited under flood-plain conditions and had a northern and western source, as indicated by crossbedding of the coarser sediments, the abundance of Coast Range and Klamath Mountain minerals and rock types, and the eastward decrease in average grain size. Based on fossil evidence, the Tehama Formation ranges in age from upper Pliocene to middle Pleistocene (Olmstead and Davis, 1961). The Tehama Formation is a very important source of ground-water in the Sacramento Valley, although its percentage of water yieding sediments varies considerably throughout the valley.

Unconformably overlying the Tehama Formation rest the poorly sorted red gravels of the Pleistocene Red Bluff Formation , and alluvial fan, stream and floodplain deposits of late Pleistocene and Recent age (Olmstead and Davis,1961). The Red Bluff Formation, named by Diller (1894), generally crops out on the elevated areas within the study area, such as terraces that are above the present day stream valleys. The Red Bluff Formation consists of coarse-grained sands and gravels containing a reddish-brown silty or sandy matrix (Olmstead and Davis, 1961). The reddish-brown color, most likely due ferric oxide staining in the matrix, is a distinct characteristic of the Red Bluff Formation, and at many places this contrasts greatly with the gray to yellow coloring that is usually characteristic of the underlying Tehama Formation (Thomasson et al.,1960). The subsurface extent of the Red Bluff Formation is not known because of the difficulty in differentiating the Red Bluff deposits from the underlying Tehama Formation or the overlying alluvial deposits, also, the Red Bluff Formation may have been erosionally removed or never deposited in some areas. The Red Bluff Formation is generally less than 50 feet thick and discontinuously caps an erosional surface cut into the Tehama Formation (Olmstead and Davis, 1961) (Figure 3).

The younger alluvium of late Pleistocene and Recent age generally consists of unconsolidated gravel, sand, silt, and clay, and unconformably rests on either the Red Bluff Formation or the Tehama Formation. These sediments range from less than five feet to approximately 150 feet thick in the study area.

Figure 3. Erosional unconformity between the Pleistocene Red Bluff Formation and the Upper Pliocene Tehama Formation. Road cut for I-505, near Madison, California. January, 1955. (C.G. Higgins).

STRUCTURAL FEATURES

Structural features in the study area include the Dunnigan Hills Anticline, the Plainfield Ridge, the Sweitzer Fault, and the Zamora Fault (Plate 1) as well as other features dicussed below.

The Dunnigan Hills structure, which extends into the north-central portion of the study area, is a gas producing, doubly plunging, north-west trending anticline (Harwood and Helley,1987). The east flank of the Dunnigan Hills anticline is bounded by the Zamora Fault (Harwood and Helley). Data from a recent well drilled near Zamora, California, by the Water Resources Division of the U.S. Geological Survey has provided new information on the amount of late Cenozoic deformation of the Dunnigan Hills area. According to Harwood and Helley (1987), a volcanic ash bed penetrated at depth by the hole drilled by the Geological Survey has been correlated with ash beds occurring directly above the Red Bluff gravels elsewhere in the valley. It was assumed that the ash bed overlies the Red Bluff Formation in the Zamora well and that there is a minimum of about 660 feet of vertical displacement of the Red Bluff Formation. This vertical diplacement is interpreted to be the result of folding on the Dunnigan Hills anticline and displacement on the Zamora Fault.

The Plainfield Ridge, which is located in the south portion of the study area, is comprised of a series of low lying hills rising only 10-25 feet above the alluvial plain. Olmstead and Davis (1961) describe the Plainfield Ridge as being an isolated body of dissected alluvial deposits, which extends northwest-ward ten miles from Putah Creek towards Cache Creek and covers an area of 15,230 acres. Kirby (1943) interpreted the Plainfield Ridge as an anticline, with its axis trending approximately parallel to the Dunnigan Hills anticline. The Plainfield Ridge anticlinal axis appears to trend about southeast and plunge in a southeatsward direction, although the surface topography suggests that the axis may curve to the south just north of Putah Creek (Thomasson et al., 1960).

The Sweitzer Fault, which is located in the northwest portion of the study area, has been interpreted by Wagner (1984) to be a west dipping normal fault which places upper Cretaceous rocks on the east in contact with the Tehama Formation on the west. Redwine (1972) proposed that the Sweitzer Fault was the northwest continuation of the Midland Fault. The Midland Fault, postulated from well logs by Jennings (1975) and Wagner (1981), has been shown to trend northwestward in a broad zone from the Sacramento Delta northwest of Stockton, towards Winters.

Reynolds and Reynolds (1987) mapped subsurface faults based on borehole data, and show the basement of this region to be broadly incised by northwest-trending faults.

Harwood and Helley (1987) also mapped northwest-trending faults in the area under investigation in their study of the late Cenozoic tectonism of the Sacramento Valley. They concluded that for the past 2.5 million years, and probably much longer, deformation in the valley has occurred in a regional stress field in which the maximum horizontal component of compressive stress was oriented approximately east-west and the minimum component of stress (maximum extension) was oriented approximately north-south. They also concluded that within this stress regime, strain has been released primarily by reverse movement on north- and northwest-trending high-angle faults and associated folding in the sedimentary rocks of the valley fill. This is in disagreement with Wagner's (1984) interpretation of the Sweitzer Fault being a west-dipping normal fault.

ELEVATION OF THE TOP OF THE TEHAMA FORMATION

METHODS USED

Of the 809 well locations observed in this thesis, 396 well sites contained point-resistance, spontaneous potential, and driller's logs, while the remaining 403 well locations contained only point-resistance and spontaneous potential logs. All of the electric logs and driller's logs from each of the 809 well locations were analyzed in an attempt to determine the contact between the Tehama Formation, and the overlying Red Bluff Formation or alluvial deposits. The contact was identified on the basis of the resistance and potential differences of the alluvial sediments, and correlated to the descriptions of the materials on the driller's logs.

Ohm's Law, which provides the basic principle for logging devices that measure resistance, states that the rate of current flow , I, through a conductor is porportional to the potential or voltage difference causing that flow, E, and inversely proportional to the resistance of the medium, r. Ohm's Law can be expressed as:

$$r = E / I$$

in which r = resistance , in ohm's ; E = potential , in volts ; and, I = current , in amperes.

The resistance of any medium is not only dependent on the physical composition of that medium, but is also dependent on the cross-sectional area and length of the path through that medium. Point resistance systems measure the resistance, in ohms, between an electrode in the well and an electrode at the land surface, or between two electrodes in the well (Figure 4). Because no provision exists for determining the length or cross-sectional area of the travel path of the current, the measurement is not an intrinsic characteristic of the material between the electrodes. Single-point resistance logs cannot be used for quantitative interpretation of porosity or other hydraulic parameters, but are excellent for lithologic information due to their unique response to changes in lithology. Deflections on the resistance logs are interpreted as changes in lithology. Typically, resistance increases in sands and sandstones, and decreases in siltstones and clays (Keys and McCary).

Spontaneous potential logs are records of the natural potentials developed between the borehole fluid and the surrounding rock materials (Keys). The spontaneous-potential log is used chiefly for geologic correlation, determination of bed thickness, and separating porous from non-porous rocks in shale-sandstone and shale-carbonate sequences. The spontaneous-potential log is a graphic plot of the small differences in voltage, measured in millivolts, that develop at the contacts between the borehole fluid, the shale or clay, and the water in the aquifer (Keys and McCary). Spontaneous-potential is a function of the chemical activities of fluids in the borehole and adjacent rocks, the temperature, and the type and quantity of clay present; it is not directly related to porosity and permeability (Keys).

Spontaneous-potential deflections are generally recorded on the left hand track of the electric log, with deflections to the left considered as negative,

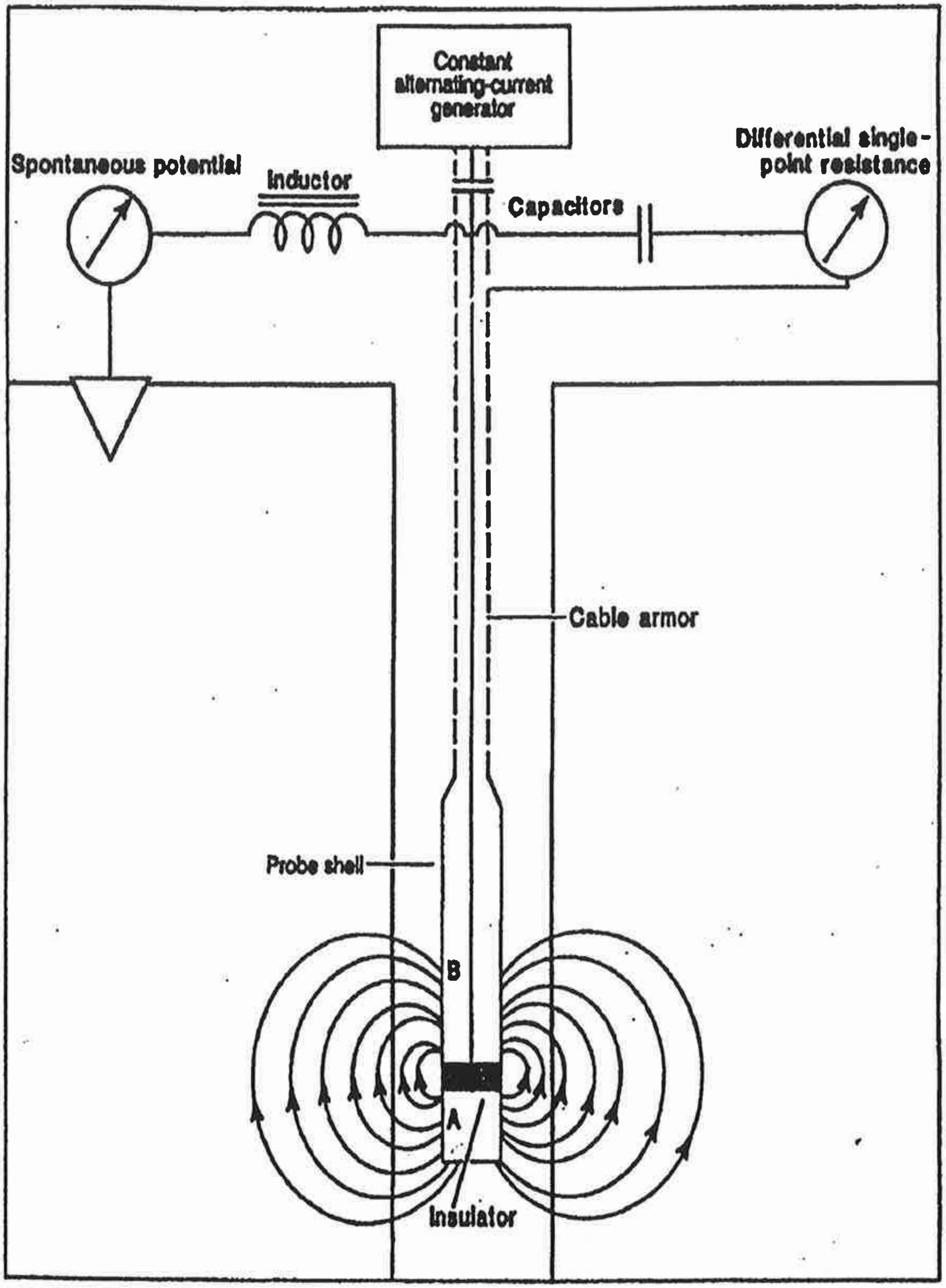

Figure 4. System used to make single-point resistance and spontaneous-potential logs. From Keys, 1988.

and those to the right considered as positive. Lithologic contacts are located at the point of curve inflection, where the current density is maximum. In a borehole where the drilling mud is considered fresher than the formation water, maximum positive potential deflections represent intervals of fine-grained material, such as clay or silt, and maximum negative deflections represent coarser sediments.

Both point-resistance logs and spontaneous-potential logs are affected by conductivity of the borehole fluid and formation fluid, changes in borehole diameter, casing in the hole, and noise generated from the logging devices. If the borehole fluid is more saline than the formation fluid, the spontaneous-potential responses will be reversed, giving positive potentials opposite sand beds and negative potentials opposite clays and shales. If the formation has a higher resistance than the borehole fluid, the majority of current will flow through the borehole fluid , and only a small amount will flow through the formation. As a result, formations with high resistance will not significantly affect the flow of current and may be difficult to distinguish if the single-point method is used in salty mud or brine-filled holes (Keys and McCary).

Increases in borehole diameter, possibly due to cavings, wash-outs, or fractures, add to the cross-section of the current path through a saline borehole fluid, thus decreasing the apparent resistance, and decreasing the magnitude of the spontaneous potential recorded. Casing in the hole blocks the recording of point-resistance and spontaneous-potential logs.

Noise can be defined as any spurious or unwanted signals not due to the actual resistance or spontaneous-potential in the borehole (Keys and McCary). Varying potentials resulting from cable motion can be spontaneous-potential logs to produce noise, as well as magnetization of armored cable, currents set up by casing corrosion in the logged well, and flow of ground water through the well bore.

In this study, very few extraneous effects on the electric logs were noted. Most boreholes were known to be four inches in diameter. Where the boreholes were larger, the diameter was noted and the electric logs were assessed accordingly. The borehole fluid was known to be usually fresher than the formation fluid, therefore, standard readings were usually given by the electric logs. Ambiguous readings due to noise were usually not aparent on the point-resistance logs, although some drift in the reading, possibly due to an increase in borehole diameter, was sometimes encountered. Ambiguous readings due to noise were more frequently encountered on the spontaneous-potential logs, and assessed accordingly.

The contact between the Tehama Formation and the overlying younger alluvial sediments was determined by correlating the driller's logs descriptions with the resistances and spontaneous-potential differences of the materials under investigation. Where driller's logs described the color of the sediments, the contact was identified on the basis of reddish gravels overlying yellow clays and were correlated to similar driller's logs and electric logs. Most of the driller's logs, however, did not describe color, therefore, resistance and spontaneous- potential differences became the dominant indicator of the contact.

The highly permeable sands and gravels of the younger alluvial deposits appeared as positive deflections on the point-resistance logs, and usually strong negative deflections on the spontaneous-potential logs (Figure 5). This

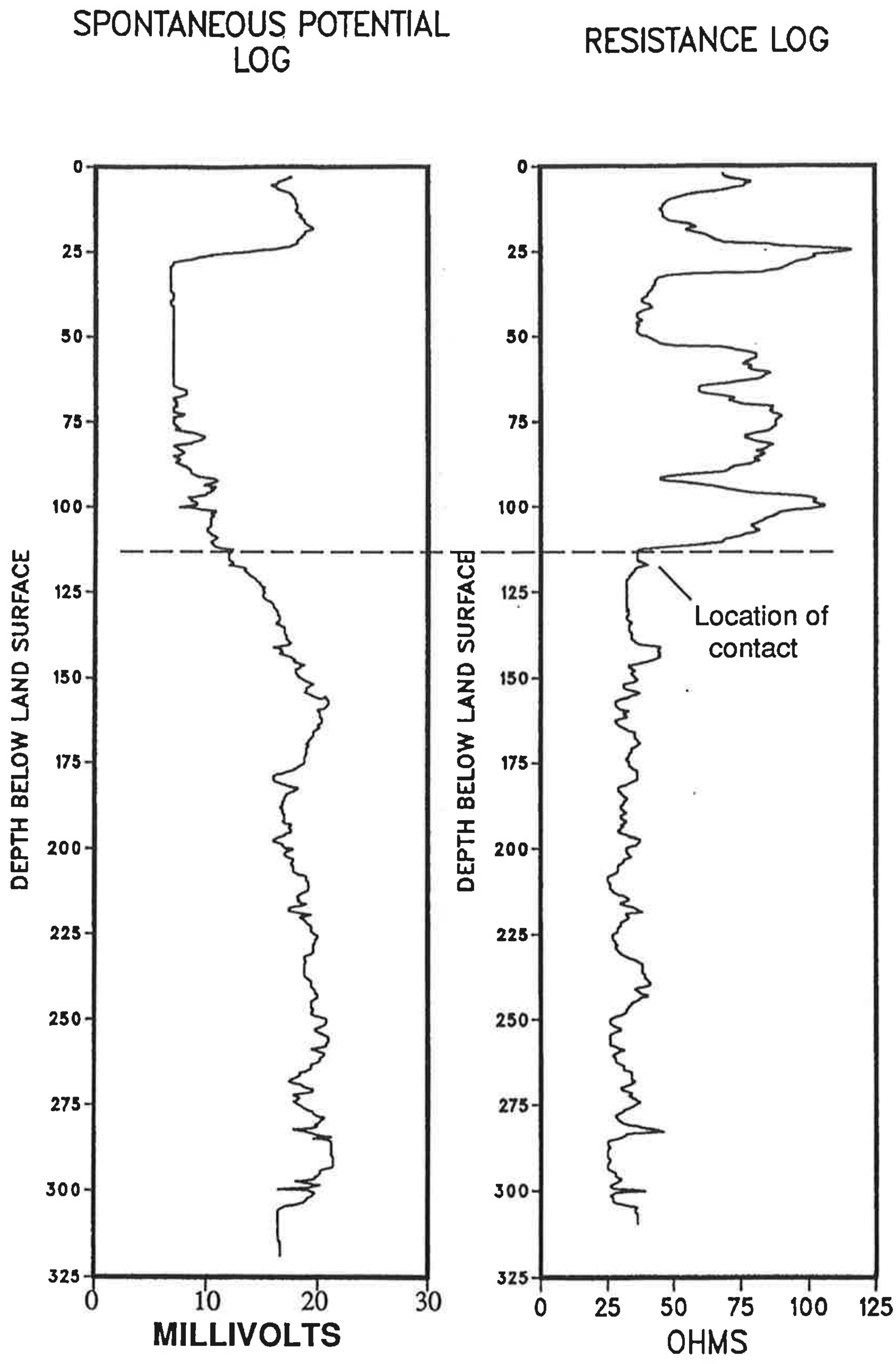

Figure 5. Example of the contact between the Tehama Formation and the younger alluvial sediments on electric logs.

was in contrast with the negative deflections on the point-resistance logs, and positive deflections on the spontaneous-potential logs given by the less permeable Tehama Formation.

Using these methods, depth to the top of the Tehama Formation was selected at 257 well locations. The elevation of the top of the Tehama Formation was determined by subtracting the depth to the contact from the elevation of land surface, estimated at each well from U.S. Geological Survey 7.5 minute topographic maps.

Using ARC/INFO, a geographic information system used to automate, manipulate, analyze, and display geographic data in digital form, each well location was digitally plotted from U.S. Geological Survey 7.5 minute topographic maps. The elevations of the top of the Tehama Formation were plotted at 257 well locations and hand contoured (Plate 2). Values of the elevation of the top of the Tehama Formation for an additional 472 well locations were estimated by interpolation from the contour map.

As cited earlier, Wahler Associates (1982), the State of California (1987), and Thomasson et al. (1960) determined the contact between the Tehama Formation and the overlying alluvial sediments in their respective studies. Each determined the elevation of the top of the Tehama Formation using driller's logs and constructed geologic cross-sections showing the contact. In this thesis, elevations of the top of the Tehama Formation for each of the three previous studies were plotted and hand contoured, allowing for a comparison of the distribution of the top of the Tehama Formation.

DISTRIBUTION OF THE TOP OF THE TEHAMA FORMATION

The contact between the Tehama Formation, and the overlying younger alluvial sediments is more prominent near the western edge of the study area, and is indicative of an erosional contact. The contact becomes less obvious in the central and eastern portions of the study area where the overlying alluvial sediments are finer grained, and the contact is characteristic of a depositional surface. In general, the Tehama Formation dips to the east and southeast, with structural highs and lows trending in a northwest direction, correlating with the northwest stress regime of the Sacramento Valley interpreted by Harwood and Helley (1987).

Electric logs and driller's logs from wells located in the elevated western portions of the study area indicate distinct contacts between the Tehama Formation and the younger alluvial sediments. These contacts are characteristic of an erosional surface, and usually are composed of less resistant sands and clays of the Tehama Formation in sharp contact with the highly resistive coarse-grained sands and gravels of the younger alluvial sediments. This contact is usually sharp and easily detected on the electric logs. In the northern regions of the Capay Valley, near Rumsey, California, 15 to 25 foot thick, highly resistant gravel beds, possibly correlating with the Red Bluff Formation, overly much less resistant clays and sands. These thick, highly resistant gravel beds are also found along the edges of the Capay Valley south to Esparto, and extend from the Coast Ranges east towards the center of the Valley, where they then grade into thinner bedded, less resistant gravels, sands, and clays.

Shallow, thick , resistant gravel beds overlying clays and sands are not as prevalent in the central and eastern portions of the study area. However, in the higher elevated areas, such as the Dunnigan Hills north of Cache Creek, and the Plainfield Ridge area south of Cache Creek, shallow, thick bedded gravels are found. Helley and Harwood (1985) mapped scattered outcrops of the Red Bluff Formation in these higher elevated areas. This writer found the Dunnigan Hills and Painfield Ridge area to consist primarily of interbedded sands and clays of the Tehama Formation which has been uplifted to the surface in these areas. The majority of wells located in these areas are located directly on the Tehama Formation. The logs from these wells describe inter-bedded clays, sandy clays, and sands to great depths. Throughout the study area, logs from wells located on the Red Bluff Formation describe thick sequences of highly resistant sands and gravels overlying the less resistant clays and sands. These contacts are relatively shallow, generally 10 to 25 feet deep. However, some of the logs from wells which are located on what Harwood and Helley mapped as the Red Bluff Formation describe less resistant clays and sands to great depths, making the determination of the top of the Tehama Formation difficult. In these areas, either the Red Bluff Formation is missing, and finer grained alluvium is overlying the Tehama Formation, or these wells are located directly on the Tehama Formation.

In low-lying regions of the study area, the contact is more difficult to determine from the logs, and may represent a depositional contact. The thick sequences of shallow, coarse-grained gravel beds are not as prominent in these areas. The contact in these areas consists primarily of interbedded coarse-grained sands , sandy clays, and some gravels overlying finer grained clays and sands of the Tehama Formation. The Red Bluff Formation is missing in most of the low-lying areas in the central and eastern portions of the study area. In some low-lying areas, however, shallow, coarse-grained gravels overly clays and sands. This is the case in the area between Woodland and Putah Creek. The contact in this area is easily determined on the electric logs.

Some of the lower-lying areas of the study area consist of fine-grained flood basin deposits directly overlying the Tehama Formation, which made determining the top of the Tehama Formation difficult. This was the case in the area just south-east of Woodland. In ths area, the Tehama Formation contains more coarse-grained material than the overlying alluvial sediments. The electric logs and driller's logs showed sand, clay, and gravel interbedded to depths of about 300 feet. Finer-grained sands, silts, and clays lie near the surface. In this case the contact was determined from driller's logs on the basis of reddish clays overlying yellow clays.

In general, the sediments are finer grained in the eastern portions of the study area, which makes determining the contact in the far eastern regions of the study area virtually impossible. This area consists mainly of fine-grained distal fan deposits from the coast ranges, and flood basin sediments deposited by Cache Creek, Putah Creek, and the Sacramento River.

The Tehama Formation dips eastward in the majority of the study area, and southeastward in the area just north of the city of Davis, and south to Dixon. Structural highs and lows trending north are apparent on the contour map of the top of the Tehama Formation (Plate 2). An upwarp correllating with the Dunnigan Hills Anticline exists in the north-central portion of the study area, with an axis trending northwest, and its nose plunging in an almost due south direction. A downwarp exists west of the Dunnigan Hills, and trends in a north-westwardly direction, with its axis paralleling the axis of the Dunnigan Hills Anticline. Harwood and Helley (1987) also mapped the Madison Syncline in this area.

South of these structures, between Putah and Cache Creeks, there exists a series of three structural highs trending in a north-westwardly direction. These structural highs align with the Plainfield Ridge, and may represent an anticlinal structure that has been erosionally dissected creating the three dome-like structures. Structural offset by northeast-trending faults may have also created the three dome-like structures, although it is unlikely due to the northwest structural regime of the Sacramento Valley.

In general, the top of the Tehama Formation determined in this thesis was shallower than that determined by Wahler Associates (1982) (Plate 3). Wahler Associates determined the contact between the Tehama Formation and the overlying alluvial sediments to be as much as 200 feet deeper in some locations. The contour map of the top of the Tehama Formation as chosen by Wahler Associates shows the Tehama Formation to be generally dipping to the east in the far western and eastern portions of Cache Creek , with structural highs and lows in the middle portions of the Cache Creek.

According to Wahler Associates (Plate 3), a structural high exists in the Dunnigan Hills area. The elevation of the top of the Tehama Formation determined by Wahler Associates in this area correlates well with the elevations determined in this thesis. A structural low just east of the Dunnigan Hills area trends in a rough northwest direction, and correlates well with the synclinal structure mapped in this thesis, although Wahler Associates have chosen the top of the Tehama Formation to be as much as 60 feet deeper in these areas.

The contacts determined by the State of California (1987) also tend to be deeper than the contacts chosen in this report, although generally only by 20 to 40 feet (Plate 3). Only wells located on the western and nothern portions of the proposed site of the super conducting supercollider ring were deep enough to penetrate the contact between the Tehama Formation and the overlying alluvial sediments. Contours of the top of the Tehama Formation show the formation to be gently dipping to the east near Woodland, California, and to the southeast near Dixon, California, correlating well with the structure interpreted in this thesis, although the elevations of the top of the Tehama Formation ranged from 10 to 60 feet deeper in these areas.

The contacts chosen by Thomasson et al. (1960) agree with the contacts determined in this thesis, usually to within 10 to 15 feet (Plate 3). Contours of the elevations of the top of the Tehama Formation show the Tehama Formation dipping to the east along Putah Creek, and to the southeast near Dixon, agreeing with the structure interpreted in this thesis.

There are two locations where the study areas of the previous investigations overlap; just southeast of Woodland, and south of Putah Creek between Winters and Dixon. In the area southeast of Woodland, the contacts chosen by Whaler Associates are between 80 to 150 feet deeper than the contacts chosen by the State of California. In the area between Winters and Dixon, the contacts chosen by Thomasson et al. are between 20 to 40 feet shallower than the contacts chosen by the State of California.

The discrepancies in the location of the top of the Tehama Formation between this thesis and previuos investigators could be due to the fact that determinig the vertical and lateral location of the top of the Tehama Formation was not a primary objective of these previous studies mentioned, but rather a lessor component of their respective studies. A structure map of the elevation of the top of the Tehama Formation was not published by any of these previous investigators.

COMPARISON OF DRILLER'S LOGS AND ELECTRIC LOGS AS A SOURCE OF ALLUVIAL TEXTURE INFORMATION

APPROACH

In the past, driller's logs have been used to determine sediment and lithologic characteristics in order to estimate aquifer hydraulic parameters such as specific yield, storativity, and hydraulic conductivity. Driller's logs have been considered to be an unreliable source of hydrogeologic information by some investigators, while other investigators consider driller's logs to be an excellent source of hydrgeologic information. This thesis provides the first quantitative analysis of driller's logs as sources of alluvial sediment texture information

In this thesis, the texture of alluvial sediments is considered to be coarse-grained or fine-grained. Coarse-grained sediment as determined from the driller's logs is considered to consist mainly of sand, clayey and silty sand, gravel, and clayey, silty, or sandy gravel. Coarse-grained sediment determined from electric logs is sediment showing high positive deflections on the point-resistance logs and usually low negative deflections on the spontaneous-potential logs. Fine-grained sediment as determined from the driller's logs consists mainly of clay, silt, and sandy clay or silt. Fine-grained sediment determined from electric logs is sediment showing low negative deflections on the point-resistance logs, and usually positive defelctions on the spontaneous-potential logs.

To determine whether or not the driller's logs could be considered as a reliable source of alluvial texture information, two independent texture data bases were produced. The first data base was generated from alluvial texture information obtained from 396 driller's logs, while the second data base was generated from alluvial texture information obtained from 396 electric point-resistance logs, and spontaneous potentoal logs. In each case, a simplified texture classification scheme was defined and the texture and thickness of the sediments penetrated by the well were determined. Because most of the electric logs were collected from four inch test holes drilled specifically for electrical logging, and because extraneous effects on the electric logs were minimal, it was assumed that the electric logs correctly represent the texture of the alluvial sediments. This allowed for a comparison of the texture data obtained from the driller's logs to that of the actual texture of the alluvial sediments.

The driller's logs were analyzed according to driller's descriptions of the sediments penetrated by the well. Driller's descriptions were classified as coarse-grained, fine-grained, missing, or ambigious. Ambiguous data were due to ambiguous lithologic descriptions for a single depth interval. Data missing from the driller's logs were most often due to holes not being logged to their complete depth, or a missing description within a depth interval. In this report, missing data and ambiguous data were treated identically. For example, an interval reported on the driller's log would be classified as:

Depth Interval	Driller's Description	Texture Classification
0 - 10 feet	clay	Fine grained
10 - 15 feet	sandy gravel	Coarse grained
15 - 25 feet	sand and clay	Ambiguous
25 - 40 feet		Missing
45 - 50 feet	sandy clay	Fine grained

A more detailed classification of the alluvial texture, for example three classifications of coarse-, medium-, and fine-grained, was not feasible because of the inconsistent quality of the driller's logs.

The driller's logs were also rated qualitatively as poor, fair, good, or excellent, based on the detail of the descriptions used by the driller (Table 2). The quality rating was based on the assumption that the more detailed logs provide a more accurate basis for the classification of alluvial texture. A driller who takes the time to describe color, lithology, hardness, water-bearing nature etc. will most likely produce a log that contains more accurate alluvial texture information.

Table 2. Procedure for rating the quality of driller's logs.

Description	Quality
Clay sand clay gravel	Poor
Clayey sand coarse sand silt fine sand	Fair
Brownish-yellow fine sand blueish silty clay coarse sand	Good
Sandy clay, clay 60 percent, light olive gray 5Y5/2; olive grey, very fine to fine grained sand	Excellent

Alluvial texture information was derived from the electric logs according to the resistance and spontaneous potential of the alluvial materials. As previously mentioned, resistance logs do not provide a quantitative measurement of resistance or porosity, however, they are excellent for determining bed boundaries and lithologic contacts between coarse- and fine-grained material. Each log was independently examined and intervals of alluvial material were identified as either fine-grained, coarse-grained, or missing (Figure 6). None of the information on the electric logs was judged to be ambiguous. Alluvial material giving high positive deflections on the point resistance logs and low negative deflections on the spontaneous potential logs indicated coarse-grained sediment. Low negative deflections on the point-resistance logs and high positive deflections on the spontaneous potential logs indicated fine-grained sediment. Intervals of missing logged information were generally located at the top or bottom of the hole. The missing data at the bottom of the hole are most likely due to caved sediments accumulated at the bottom of the hole restricting complete logging. The missing data at the top of the hole are most likely due to the effects of surface casing, or due to the probe exiting the drilling fluid or formation fluid during logging of the hole. For this thesis, all the alluvial sediment represented by the electric logs was classified as being coarse-grained, fine-grained, or missing.

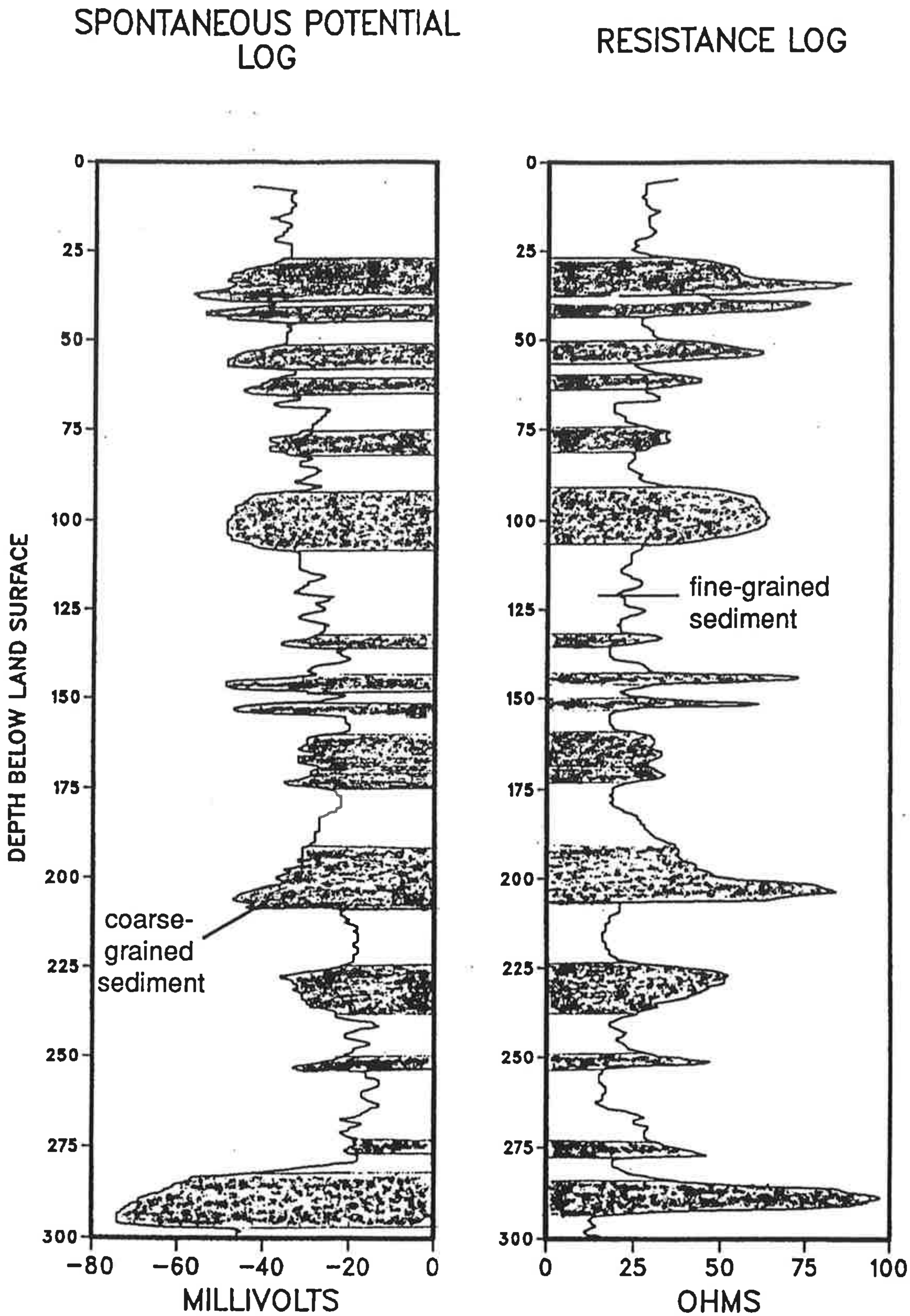

Figure 6. Sample texture classification from electric logs.

The 396 wells that contained both driller's logs and electric logs were used to compare the quality of alluvial texture information. For each well, alluvial texture data compiled from both types of logs described the same number of feet of alluvium. Of the 396 wells, two are over 1,180 feet deep, and the mean depth is 395 feet (Figure 7). Using both texture data bases, and a computer program written by Eric Lorenz of the U. S. Geological Survey, Water Resources Division (1988), and later modified by Hugh Mitten, Bryce Jaccobs, and Larry Zinky of the U. S. Geological Survey, Water Resources Division (1989), the total number of feet of fine- grained material, total number of feet of coarse-grained material, and the total number of feet of missing data or ambiguously described material, along with percentages of each was computed for selected depth intervals.

RESULTS

Of the 396 driller's logs analyzed, 44 were of poor quality, 309 were fair, 43 were good, and none were judged to be excellent (Table 3). The majority of alluvial texture information obtained from driller's logs was from driller's logs of fair quality. Most missing or ambiguous data, approximately 9%, was obtained from good quality driller's logs, while the least amount of missing or ambiguous data,

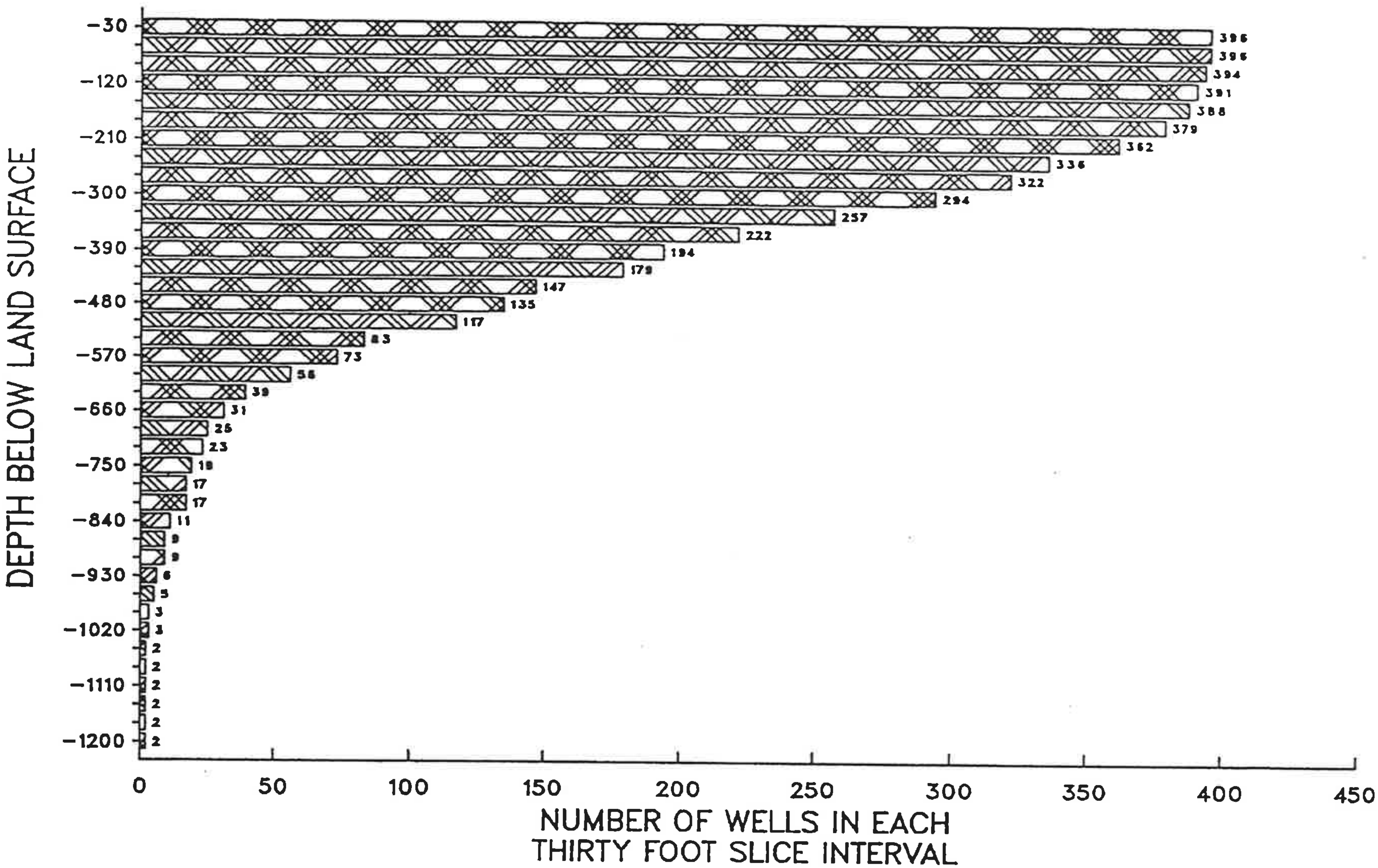

Figure 7. Variation of the number of wells with depth.

	GOOD	FAIR	POOR
TOTAL NUMBER OF LOGS	43	309	44
TOTAL FEET DRILLED	15,158	126,305	14,336
TOTAL FEET COARSE GRAINED SEDIMENT	3,307 (21.8%)	30,907 (24.5%)	5,189 (36.2%)
TOTAL FEET FINE GRAINED SEDIMENT	10,470 (69.1%)	86,940 (68.8%)	8,282 (57.8%)
TOTAL FEET MISSING OR AMBIGUOUS MATERIAL	1,381 (9.1%)	8,458 (6.7%)	865 (6.0%)

TABLE 3. Comparison of alluvial material coded from driller's logs of poor, fair, and good quality.

approximately 6%, was obtained from poor quality driller's logs. The low percentage of missing or ambiguous data obtained from the driller's logs of poor quality is due to the driller's single-word description of alluvial sediments. These descriptions, such as sand, gravel, clay, are texturally unambiguous. The high percentage of missing or ambiguous texture data obtained from the driller's logs of good quality is due to more detailed descriptions used by the driller that sometimes designates a single depth interval as being both coarse and fine. Most of the missing or ambiguous data from the good quality driller's logs was actually ambiguous; very few depth intervals were undescribed on good quality driller's logs.

Ideally, the comparison of driller's log quality should include an evaluation of the location, geology, and individual drillers of the well logged. Because these wells were drilled by drillers with varying amounts of expertise, it is difficult to compare the alluvial texture information obtained from each quality log.

Comparring the 155,799 feet of alluvial texture information in both data bases shows that the driller's logs underestimate the amount of coarse-grained material by as much as 10,000 feet (6.4%), overestimate the amount of fine-grained material by over 3,000 feet (2.1%), and contain approximately 2.5 times the amount of missing or ambiguous material (Table 4). When omitting the missing intervals from the electric log texture data to compare only the

	DRILLER'S LOGS			ELECTRIC LOGS		
DATA QUALITY	GOOD, FAIR, AND POOR	GOOD AND FAIR	GOOD	CORRESPONDING ELECTRIC LOGS		
NUMBER OF LOGS	396	352	43	396	352	43
TOTAL FEET COARSE	39,403	34,214	3,307	49,333	43,751	4,601
TOTAL FEET FINE	105,692	97,410	10,470	102,415	94,080	9,958
TOTAL FEET MISSING OR AMBIGUOUS	10,704	9,839	1,381	4,051	3,632	599
TOTAL FEET DRILLED	155,799	141,463	15,158	155,799	14,463	15,158

TABLE 4. Comparison of alluvial texture information obtained from driller's logs and electric logs.

	DRILLER'S LOGS			ELECTRIC LOGS		
DATA QUALITY	GOOD, FAIR, AND POOR	GOOD AND FAIR	GOOD	CORRESPONDING ELECTRIC LOGS		
NUMBER OF LOGS	396	352	43	396	352	43
TOTAL FEET COARSE	38,856	33,730	3,816	49,333	43,751	4,601
TOTAL FEET FINE	102,209	94,283	10,003	102,415	94,080	9,958
TOTAL FEET MISSING OR AMBIGUOUS	10,683	9,818	1,370	0	0	0
TOTAL FEET DRILLED	151,748	141,463	15,158	151,748	137,831	14,559

TABLE 5. Comparison of alluvial texture information obtained from driller's logs and electric logs, with the missing intervals on electric logs omitted from both data bases.

actual coarse- or fine-grained intervals to the same depth intervals on the driller's logs, it is shown that the driller's logs under-estimate the tatal feet of coarse-grained material by more than 11,000 feet (6.9%) (Table 5). In this case, the total feet of fine-grained material determined from the driller's logs is roughly equal to the amount coded from the electric logs. This indicates that most of the missing or ambiguous material from the driller's logs is coarse-grained sediment.

The difference between the total feet of coarse-grained material for each log type is greatest in the shallower regions of the study area (Figure 8). In the first 30 feet below land surface, the driller's logs underestimate the amount of coarse-grained material by more than 2,200 feet (49%). The difference in the amount of coarse-grained material is greatest between land surface and approximately 300 feet below land surface. This relationship is also shown by the variation of the mean percentage of coarse-grained alluvium (Figure 9). Below approximately 300 feet, the mean percentage of coarse-grained alluvium logged by the drillers is closer to the mean percentage of coarse-grained alluvium derived from the electric logs. In the shallow alluvium the difference is the greatest, being as much as 35% different. The shallow alluvium contains the majority of the screened intervals in the wells located within the study area, therefore it is assumed that most of the groundwater withdrawl occurs in the shallow

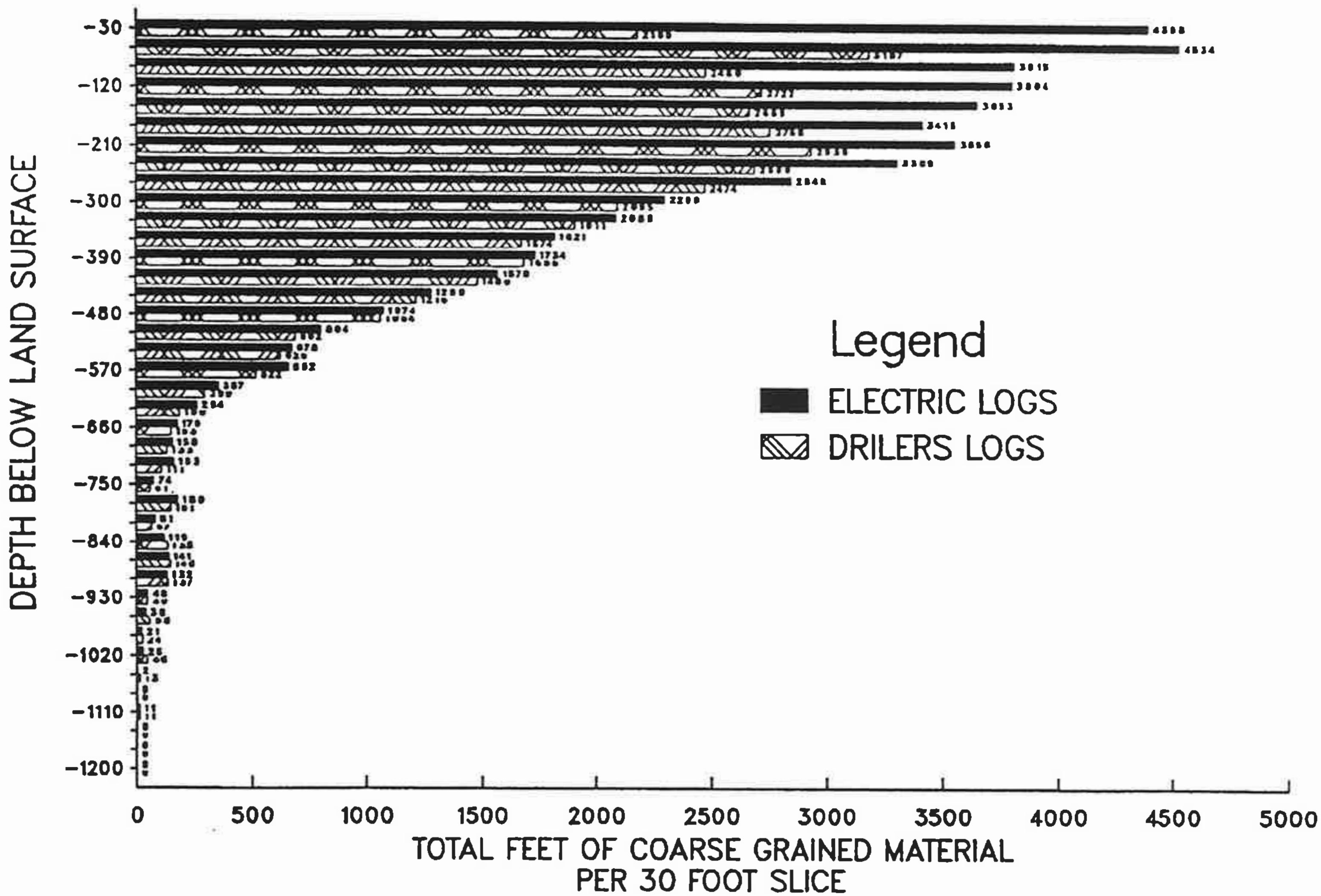

FIGURE 9. Comparison of the total feet coarse-grained material coded from driller's logs and electric logs.

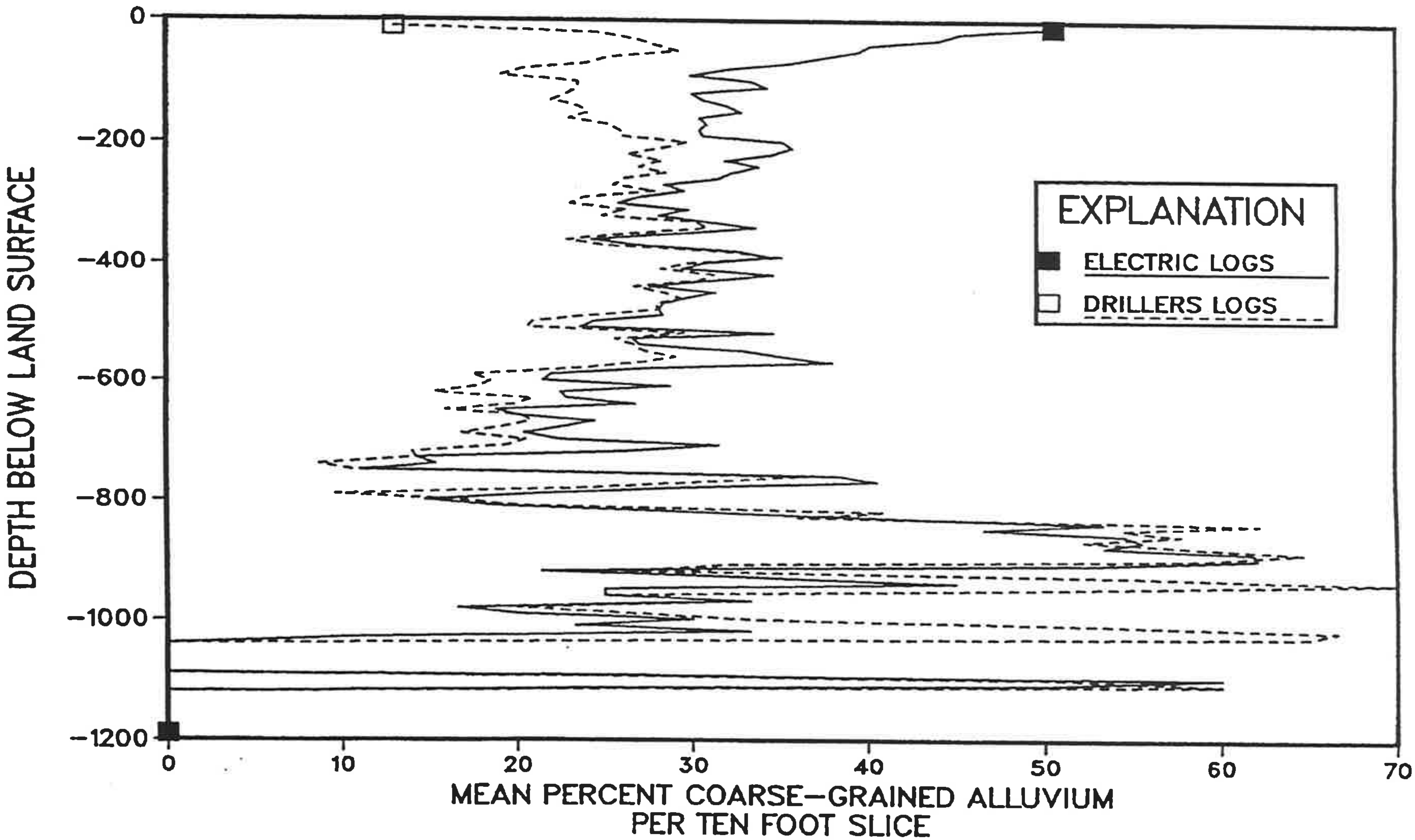

Figure 10. Comparison of the mean percentage coarse-grained alluvium between driller's and electric logs.

alluvium. Underestimating the amount of coarse-grained sediment in the shallow alluvium could lead to underestimation of aquifer parameters.

The mean percentage of missing or ambiguous data found in the driller's logs increases with depth (Figures 10 and 11), and ranges from less than 5% near the surface to more than 20% in the deeper portions of the study area. The increase in ambiguous or missing texture data with depth could be due to cuttings from coarse- and fine-grained layers mixing in the drilling fluid as they travel from the drilling bit at the bottom of the hole to the surface.

Since the driller's logs underestimate the amount of coarse-grained material, and contain more missing or ambiguous alluvial texture information, the electric logs are found to provide more accurate information of the alluvial texture within the study area. The driller's logs can provide valuable alluvial texture information for the intervals of missing data on the electric logs.

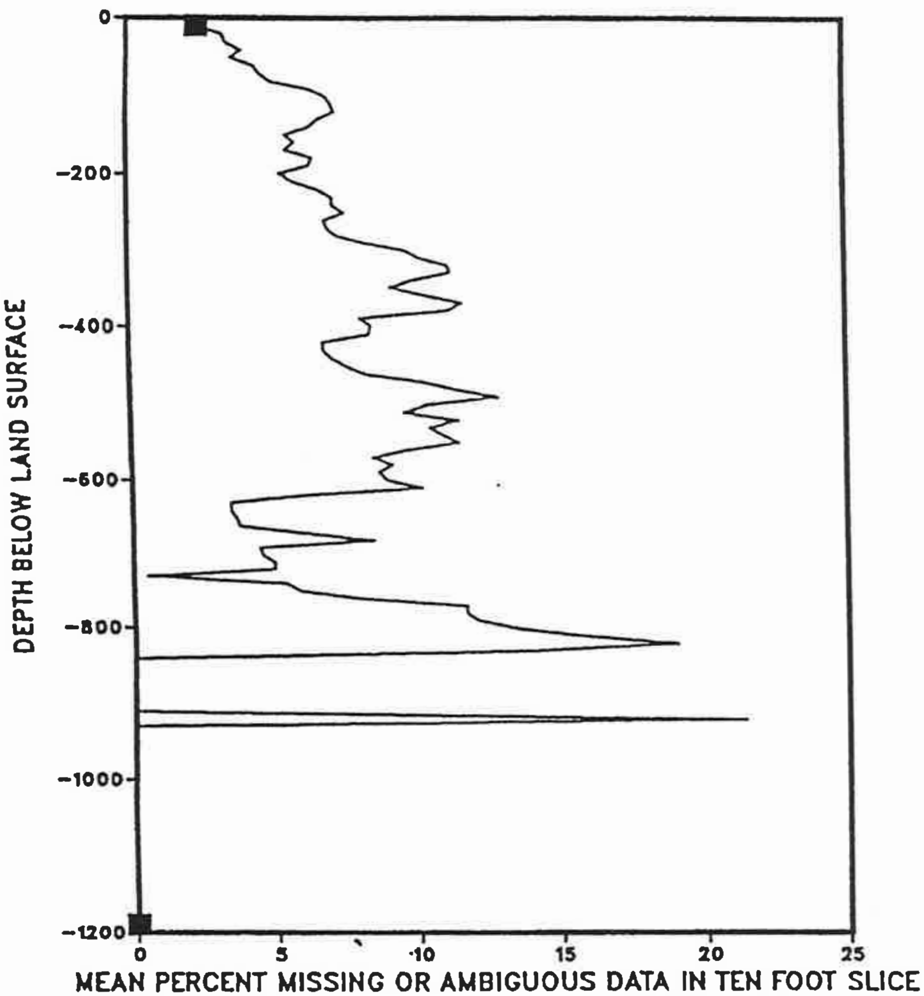

Figure 11. Mean percentage missing or ambigous alluvial texture in driller's logs.

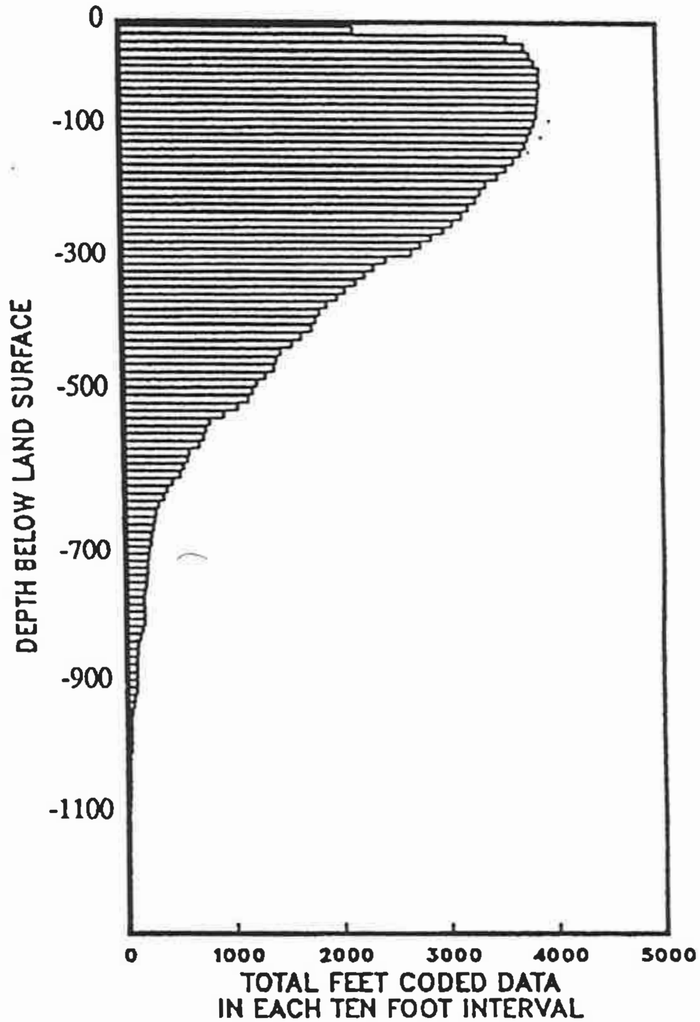

Figure 12. Variation of total coded alluvial texture information with depth.

the 125 to 150 foot depth interval (Plate 8) are located south of Putah Creek near Dixon and east of Woodland nèar the Sacramento River. Electric logs and driller's logs from wells located east of Woodland near the Sacramento River describe 10 to 30 foot thick sand and gravel beds, with interbedded sandy clays, and were most likely deposited by the Sacramento River.

The younger alluvial sediments are coarsest in the 150 to 175-foot depth interval, where coarse-grained sediments make up nearly 76% of the alluvial materials. It is often in the depth intervals directly above the top of the Tehama Formation that the younger alluvial sediments are coarsest. These coarse-grained deposits could be the gravels of the Red Bluff Formation, eroded and reworked sands and gravels associated with the Red Bluff Formation, or channel deposits of Putah and Cache Creeks, or the Sacramento River.

TEHAMA FORMATION

The distribution of the percentage of coarse-grained alluvial sediment in the Tehama Formation is shown for each 50-foot depth interval from the top of the Tehama Formation to 400 feet below the top of the Tehama Formation (Plates 11,12,13,14, 15,16,17, and 18). The top of the Tehama Formation was used as the datum from which the depth intervals were defined so that the effect of post-depositional structure deformation could be removed. This was done to determine if depositional environments or trends could be detected at each time-equivalent interval within the Tehama Formation. However, because the top of the Tehama Formation, as mapped in this thesis, is an erosional surface, the depth intervals are not exactly time-equivalent. Each map represents the author's best estimate of a time-equivalent interval of deposition of Tehama Formation sediments.

In total, the upper 400 feet of the Tehama Formation is composed of 27% coarse-grained sediments and 73% fine-grained sediments which were probably deposited mainly under flood-plain conditions. Abrupt changes in alluvial texture over relatively short distances indicate changes in local depositional environments. Depositional environments such as alluvial fans and associated braided stream channels are hard to detect due to widely spaced wells throughout the study area that decrease in number with depth. Fine-grained sediments are predominant throughout the study area, although coarse-grained sediments are typically found in areas south of Cache Creek, and along the Sacramento River east of Woodland.

The distribution of the percentage of coarse-grained materials in the first 50 feet of the Tehama Formation is shown in Plate 11. Coarse-grained materials in this depth interval are mainly located south of Cache Creek, south of Putah Creek, and near the Sacramento River east of Woodland. The coarse-grained sediments between Putah and Cache Creeks are probably sediments deposited by streams antecedent to Cache Creek and its tributaries flowing in a more southerly direction. This supports Olmstead and Davis' (1961) suggestion that coarse-grained deposits south of Cache Creek in this depth interval were probabaly deposited by an antecedent of Cache Creek when it discharged into Putah Creek. Most of the gravel south of Cache Creek is located west of Woodland. Driller's and electric logs from this area show 5 to 25-foot thick sand and sandy gravel beds that for the most part fine upwards. This suggests that these sediments were probably deposited by migrating stream channels, with each upward fining sand or gravel bed representing a transition from channel deposits to flood-plain deposits. Similar fining upward sequences of sands and gravels are located north of Cache Creek and east of the Dunnigan Hills, and north of Winters, between Putah and Cache Creeks, suggesting that during the time of deposition of the upper 50 feet of the Tehama Formation, migrating stream channels were a common depositional environment.

Coarse-grained sediments located near the Sacramento River in this depth interval are most likely sediments deposited by the Sacramento River. Driller's and electric logs from wells located in this area describe 10 to 35-foot thick, upward fining, sand and gravel beds within this depth interval.

The mean percentage of coarse-grained alluvium increases in the 50 to 100-foot depth interval below the top of the Tehama Formation (Plate 12). Coarse-grained materials comprise 30% of the alluvial sediments within this depth interval, and are located in the same general areas as in the 0 to 50-foot depth interval, indicating a similar depositional environment for a long period of time. However, fine-grained materials exist in almost all regions of the study area at this depth. Sediments in this depth interval do not exhibit a fining outward from the Coast Ranges as would be expected in an alluvial fan depositional environment. These sediments were most likely deposited by slow moving flood waters, which probably extended over most of the region.

Deeper than 100 feet beneath the top of the Tehama Formation, the sediments become finer grained with depth, becoming finest in the 200 to 250-foot depth interval, where fine-grained sediments make up 76% of the alluvial sediments (Plate 15).

Depth intervals between 100 to 200 feet generally contain less than 25% coarse-grained material, although some areas west of Woodland and south of Cache Creek are predominantly coarse-grained, with some depth intervals containing greater than 75% coarse-grained sediments (Plate 13 and 14). Coarse- grained sediments in these depth intervals are also located near Winters and extend northeasterly toward Cache Creek. Electric logs from these areas show 5 to 20-foot thick sand and gravel beds which generally fine only slightly upward, and are in sharp contact with finer-grained sediments. This may indicate erosion of previosly deposited fine-grained materials, or a change in depositional environment, such as slow moving flood waters depositing finer-grained sediments changing to faster moving fluvial waters depositing sands and gravels.

In the depth interval between 200 to 250-feet below the top of the Tehama Formation (Plate 15), individual well intervals predominantly contain less than 25% coarse-grained materials. Areas that were coarse-grained at the shallower depths, such as south of Cache Creek just west of Woodland, are predominantly fine-grained in this interval. Coarse-grained sediments in this depth interval are mainly located east of Davis near the eastern portions of Putah Creek, and north of Winters between Putah and Cache Creeks. Electric logs from wells located east of Davis show, in some areas, 5 to 35-foot thick sand and gravel beds, which are possibly ancient channel deposits laid down by the Sacramento River. Further to the west, these relatively thick sands and gravels are less prominent at this depth interval.

Between 250 and 350 feet below the top of the Tehama Formation (Plates 16. and 17.), individual well intervals predominantly contain less than 25% coarse-grained sediments, and in many places, no coarse-grained sediment is found. Thick sequences of coarse-grained alluvium exist mainly north of Winters between Putah and Cache Creeks, and north of Woodland between Cache Creek and the Sacramento River. Otherwise, thick sequences of clays with minor amounts of sands and gravels are located in most areas. The coarse-grained alluvium located north of Winters was probably deposited by Cache Creek, or other lesser streams exiting the Coast Ranges, and may represent proximal alluvial fan deposits. The coarse-grained alluvium north of Woodland was likely deposited by the Sacramento River.

Thick sequences of clays are also predominant in the 350 to 400-foot depth interval below the top of the Tehama Formation (Plate 18). Coarse-grained sediments extend from north of Woodland near the Sacramento River to south of Woodland near Davis, and are most likely channel deposits of the Sacramento River. Electric and driller's logs from wells located in these areas describe thick sequences of sands and gravels with minor amount of clay.

Electric and driller's logs from wells located between Putah and Cache Creeks and south of Putah Creek describe mainly thick beds of clay with minor amounts of thinly-bedded sands and gravels. In this depth interval, the Sacramento River is the major contributor of coarse-grained material, with finer-grained flood basin materials existing in most regions of the study area.

SUMMARY AND CONCLUSIONS

The purpose of this thesis is to locate the contact between the Tehama Formation and the overlying younger alluvial sediments, and to describe the alluvial texture distribution of the overlying younger alluvial sediments and the upper 400 feet of the Tehama Formation in parts of Yolo, Solano, Colusa, and Sacramento Counties, California. Locating the contact between the Tehama Formation and the overlying younger alluvial sediments is important because of the probable differences in the relationship between alluvial sediment texture and aquifer parameters in the unconsollidated younger alluvial sediments as compared to the semiconsollidated sediments of the Tehama Formation, and also because of the disagreements in the location of the top of the Tehama Formation. A secondary objective of this thesis is to quantitatively evaluate driller's logs as a source of alluvial texture data.

The contact between the top of the Tehama Formation and the overlying younger alluvial sediments was identified from electric and driller's logs on the basis of the resistance and spontaneous potential differences of the saturated alluvial sediments, and from driller's logs on the basis of the driller's descriptions of the well cuttings. Good quality driller's logs indicated the color of the sediments and the contact was identified on the basis of reddish gravels overlying yellow clays. Most of the driller's logs, however, did not describe color; therefore, resistance and spontaneous-potential diferences of the alluvial sediments became the dominant indicator of the contact. The highly permeable sands and gravels of the younger alluvial deposits appeared as positive deflections on the point-resistance logs, and usually strong negative deflections on the spontaneous-potential logs. The less permeable clays, silts, and sands of the Tehama Formation showed the oppposite response on the electric logs.

The elevation of the top of the Tehama Formation was selected at 257 wells. The contact between the Tehama Formation and the younger alluvial sediments is more prominant near the western edge of the study area, and is indicative of an erosional surface. The contact is less obvious towards the eastern portions of the study area where deposition was more continuous and the overlying younger alluvial sediments are generally finer-grained.

Contours of the top of the Tehama Formation show a general easterly to southeasterly dip, with structural highs and lows trending in a northwest direction, correlating with the stress regime of the Sacramento Valley interpreted by Harwood and Helley (1987). An upwarp correlates with the Dunnigan Hills Anticline as mapped by Harwood and Helly and exists in the north-central portion of the study area, with an axis trending northwest, and plunges in an almost due south direction. A northwest trending downwarp exists west of the Dunnigan Hills, and correlates with the Madison Syncline mapped by Harwood and Helley. Three structural highs trending in a northwest direction are located south of the Dunnigan Hills Anticline that correlate with the Plainfield Ridge and may represent an anticlinal structure that has been erosionally dissected.

In general, elevations of the contact between the top of the Tehama Formation and the overlying younger alluvial sediments determined in this thesis were shallower than the elevations determined by Wahler Associates (1982) and the State of California (1987), but agreed well with the elevations determined by Thomasson et al (1961). The descrepancies in the location of the top of the Tehama Formation between this thesis and previous investigators could be due to the fact that determining the distribution of the top of the Tehama Formation was not a primary objective of the previous studies mentioned, but rather a lessor component of their respective studies.

To evaluate driller's logs as a source of alluvial texture information, alluvial texture data obtained from electric logs were compared to alluvial texture data obtained from driller's logs. In this thesis, texture is defined as coarse-grained or fine-grained, where coarse- grained sediments consist primarially of sand, clayey and silty sand, clayey, silty, or sandy gravel, and gravel. Fine-grained sediments consist primarily of clay, silt, and sandy clay or silt. Alluvial texture information obtained from 396 driller's logs and 809 electric logs was compiled using a simplified classification scheme that designated sediment texture data as being fine-grained, coarse-grained, missing or ambiguous. Driller's logs were also rated qualitatively as poor, fair, good, or excellent, based on the detail of the driller's descriptions. Because all of the electric logs were collected from four-inch test holes drilled specifically for electrical logging, and extraneous effects on the resistance logs were minimal, it was assumed that the texture data obtained from the electric logs correctly represent the texture of the alluvial sediments. This allowed texture data obtained from driller's logs to to be compared to that of the actual texture of the alluvial sediments.

Of the 396 driller's logs analyzed, 44 were of poor quality, 309 were of fair quality, 43 were of good quality, and none were juged to be of excellent quality. Most missing or ambiguous amount of alluvial texture data was obtained from driller's logs of good quality, while the least amount of missing or ambiguous data was obtained from driller's logs of poor quality. The high percentage of ambiguous or missing data from the good quality driller's logs is due to the more detailed descriptions logged by the driller, which can make designating a single depth interval as either coarse-grained or fine-grained difficult in some instances. The low percentage of missing or ambiguous data obtained from the poor driller's logs is due to the one-word descriptions logged by the driller, resulting in little ambiguity.

Comparing the total 155,799 feet of alluvial texture information obtained from the driller's logs to that of the electric logs showed that the driller's logs underestimate the amount of coarse-grained material by as much as 10,000 feet (6.4%), overestimate the amount of fine-grained material by over 3,000 feet (2.1%), and contain roughly 2.5 times the aount of missing or ambiguous material. Most of the missing or ambiguous material on the driller's logs is in coarse-grained intervals of alluvial sediment.

The difference between the total feet of coarse-grained material obtained from each log type is most obvious in the shallow alluvium. In the first 30 feet below land surface, the driller's logs underestimate the amount of coarse-grained materials by almost 50%. The difference between the two data bases in the amount of coarse-grained material decreases with depth. Below 300 feet, the mean percentage of coarse-grained alluvium logged by the drillers is closer to the mean percentage of coarse-grained alluvium shown on the electric logs. The shallow alluvium contains the majority of the screened intervals in wells, and most ground-water is pumped from these shallow depths. Using estimates of the amount of coarse-grained alluvium obtained from driller's logs could lead to erroneous results when calculating aquifer parameters for the shallow depths.

Since the driller's logs underestimate the amount of coarse-grained material, and contain more missing or ambiguous alluvial texture information, the electric logs were found to provide more accurate texture information, and were used to describe the vertical and lateral alluvial texture distribution of the younger alluvial sediments and parts of the Tehama Formation. Driller's logs were used to provide alluvial texture information for the missing intervals within some of the electric logs.

Younger alluvial sediments exist near land suface in most of the study area except where the Tehama Formation or the Red Bluff Formation crop out in the higher elevated areas. These sediments range in thickness from less than 5 feet in the western sections of the study area, to nearly 180 feet in the far eastern portions of the study area, and consist primarily of clay, sandy-clay, sand, sandy-gravel, and gravel. Analysis of driller's logs and electric logs indicates that the coarse-grained sand and gravel beds generally range from 5 to 30 feet thick, and generally become thinner towards the axis of the valley, although this is not always the case. Coarse-grained materials make up nearly half the total volume of sediments within the younger alluvial sediments, and reach a maximum of 76% in the 150 to 175-foot depth range. Directly above the Tehama Formation the younger alluvial sediments are coarsest. These coarse-grained sediments could be the gravels of the Red Bluff Formation, sands and gravels eroded from the Red Bluff Formation, or stream and river channel deposits.

The younger alluvial sediments are probably channel deposits and flood basin deposits laid down by Putah and Cache Creeks, their tributaries, and the Sacramento River. Thick deposits of upward fining coarse-grained alluvial sediment south of present day Cache Creek suggest that Cache Creek once flowed in a more southeasterly direction, and may have discharged into Putah Creek at sometime in the past.

Thick deposits of upward fining coarse-grained alluvial sediment south of present day Putah Creek from south of Winters east to Dixon suggest that Putah Creek also once flowed in a more southerly to southeasterly direction, and support the suggestion of Thomasson et al. (1960) that east of Winters Putah Creek has shifted its course from time to time.

Thick intervals of coarse-grained sediments east of Winters near the Sacramento River are probably Sacramento River channel deposits, and support Olmstead and Davis' (1961) suggestion that the Sacramento River channel was once located further to the west than its present day location.

The upper 400 feet of the Tehama Formation consists of 27% coarse-grained sediments and 73% fine-grained sediments and support Page's (1986) suggestion that the Tehama Formation was probably deposited under flood-plain conditions. The effects of local depositional environments are indicated by abrupt changes in alluvial texture over relatively short distances. Alluvial fans and associated braided stream channel deposits are hard to define because of the widely spaced wells that decrease in number with depth. Fine-grained sediments are predominant in all regions of the study area, although coarse-grained sediments are often located south of Cache near Woodland, and along the Sacramento River east of Woodland.

The coarse-grained sediments in the upper 100 feet of the Tehama Formation are located in roughly the same areas as the coarse-grained sediments of the younger alluvial sediments, suggesting a similar depositional environment for an extended period of time.

Below 100 feet beneath the top of the Tehama Formation, the sediments become finer-grained with depth, becoming finest in the 200 to 250 foot depth interval, where fine-grained sediments make up 76% of the alluvial sediments.

Depth intervals between 100 to 200 feet generally contain less than 25% coarse-grained alluvium, although some areas west of Woodland and south of Cache Creek are predominantly coarse-grained, with some depth intervals containg greater than 75% coarse-grained sediments.

Between 200 to 400 feet beneath the top of the Tehama Formation, thick sequences of fine-grained sediment are predominant in all regions of the study area. Most coarse-grained deposits are located in the eastern portions of the study area near the Sacramento River, and are most likely ancient channel deposits laid down by the Sacramento River.

The analysis of alluvial texture provided in this thesis provides a basis for estimation of aquifer parameters during calibration of ground-water flow models, and provides information on areas of potential land subsidence. The semi-consollidated to consollidated sands and gravels within the Tehama Formation may need to be assigned lower values of hydraulic conductivity or storage capacity than the unconsollidated sands and gravels of the younger alluvial sediments. Also, the semi-consollidated to consollidated alluvial sediments of the Tehama Formation may not be as susceptible to land subsidence as the unconsollidated younger alluvial sediments. Differentiating the texture distribution of the alluvial sediments of the Tehama Formation from the younger alluvial sediments allows each to be considered separately when estimating aquifer parameters, and identifying potential areas of land subsidence.

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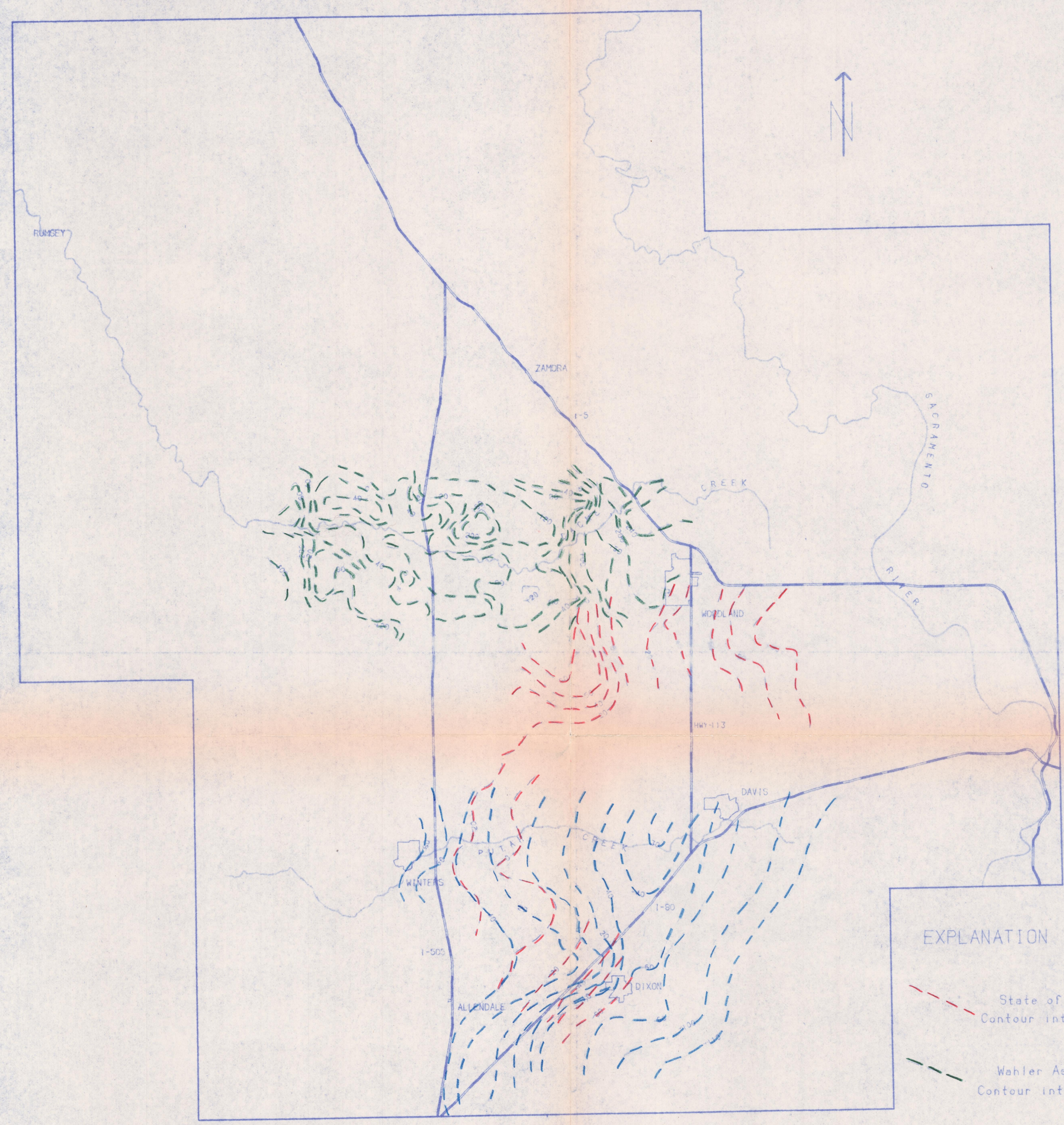

EXPLANATION

State of California
Contour interval 20 feet

Wahler Associates
Contour interval 40 feet

Thomasson et al.
Contour interval 20 feet

PLATE 3. Contour map of the elevation of the top of the Tehama Formation compiled from State of California (1987), Wahler Associates (1982), and Thomasson et al. (1960).

0 2 4 6 MILES

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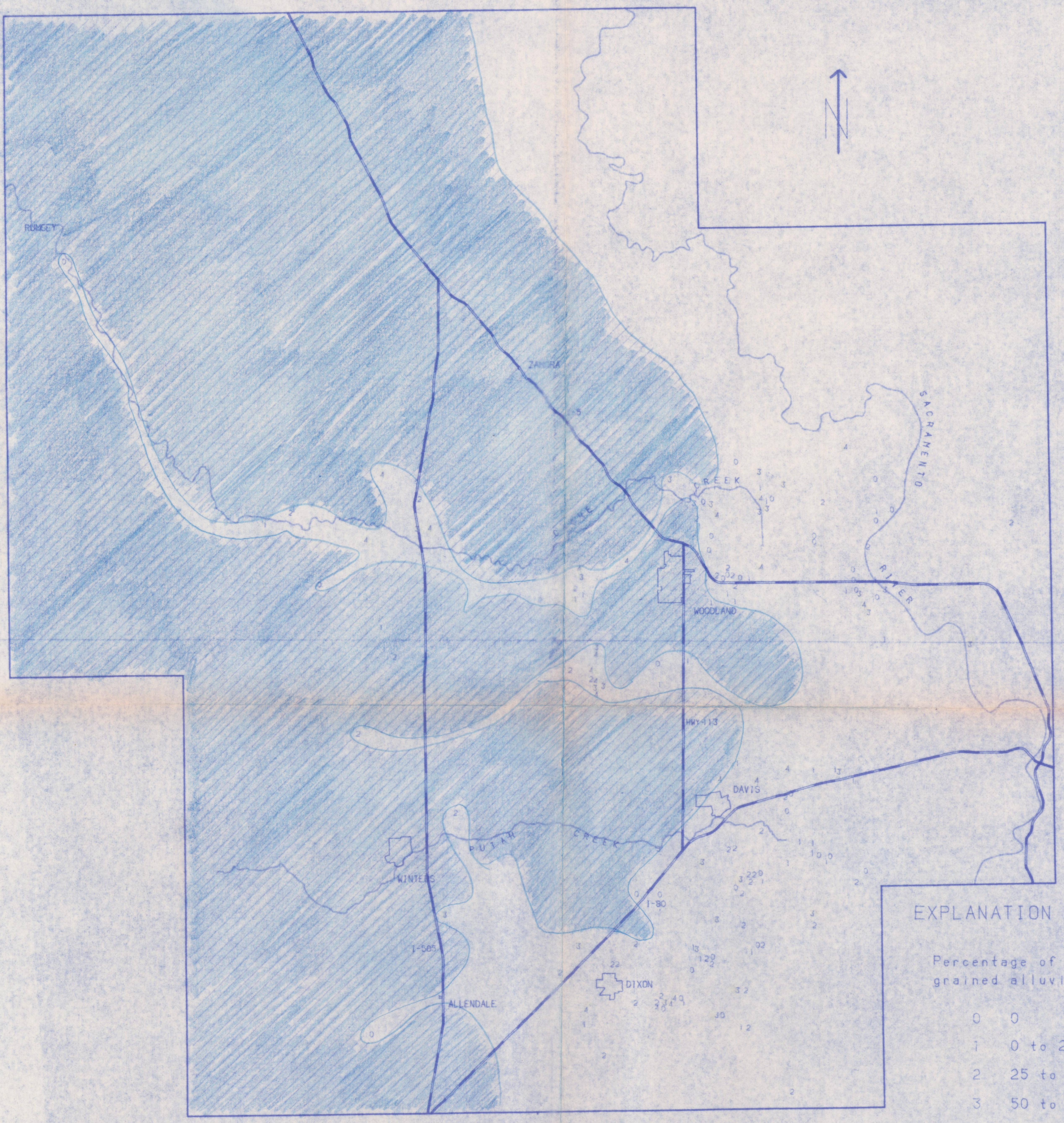
Texture Distribution of the Younger Alluvial Sediments and Parts of the Tehama Formation in Portions of Yolo, Solano, Colusa, and Sacramento Counties, California.



EXPLANATION

Percentage of coarse-grained alluvium:

0 0
1 0 to 25
2 25 to 50
3 50 to 75
4 75 to 100

Tehama Formation and older rocks.

PLATE 7. Distribution of the percentage of coarse-grained sediments within the 75 to 100 foot depth interval of the younger alluvial sediments.

0 2 4 6 MILES

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Texture Distribution of the Younger Alluvial Sediments and Parts of the Tehama Formation in Portions of Yolo, Solano, Colusa, and Sacramento Counties, California.

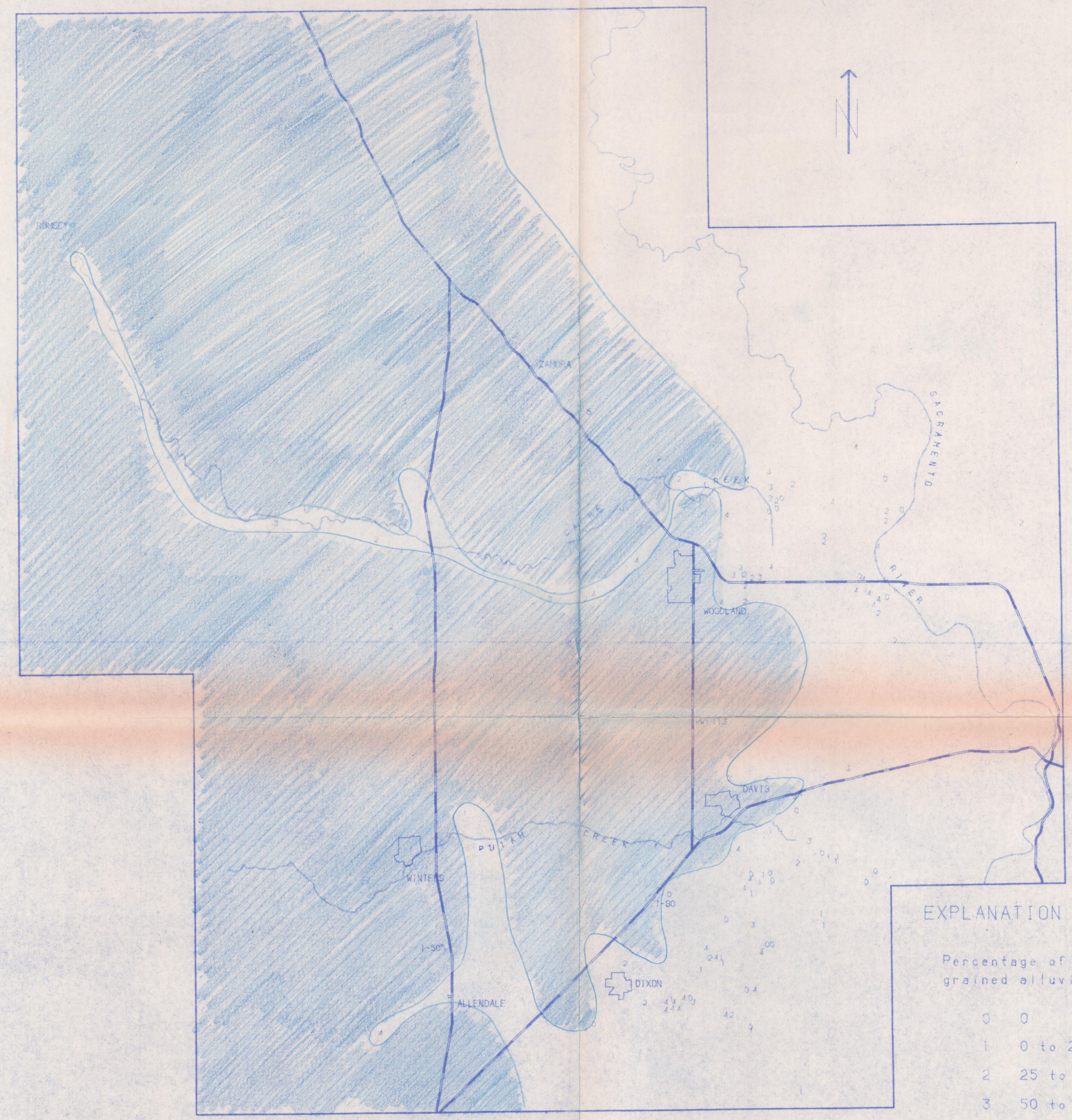


PLATE 8. Didtribution of the percentage of coarse-grained sediments within the 100 to 125 foot depth interval of the younger alluvial sediments.

0 2 4 6 MILES

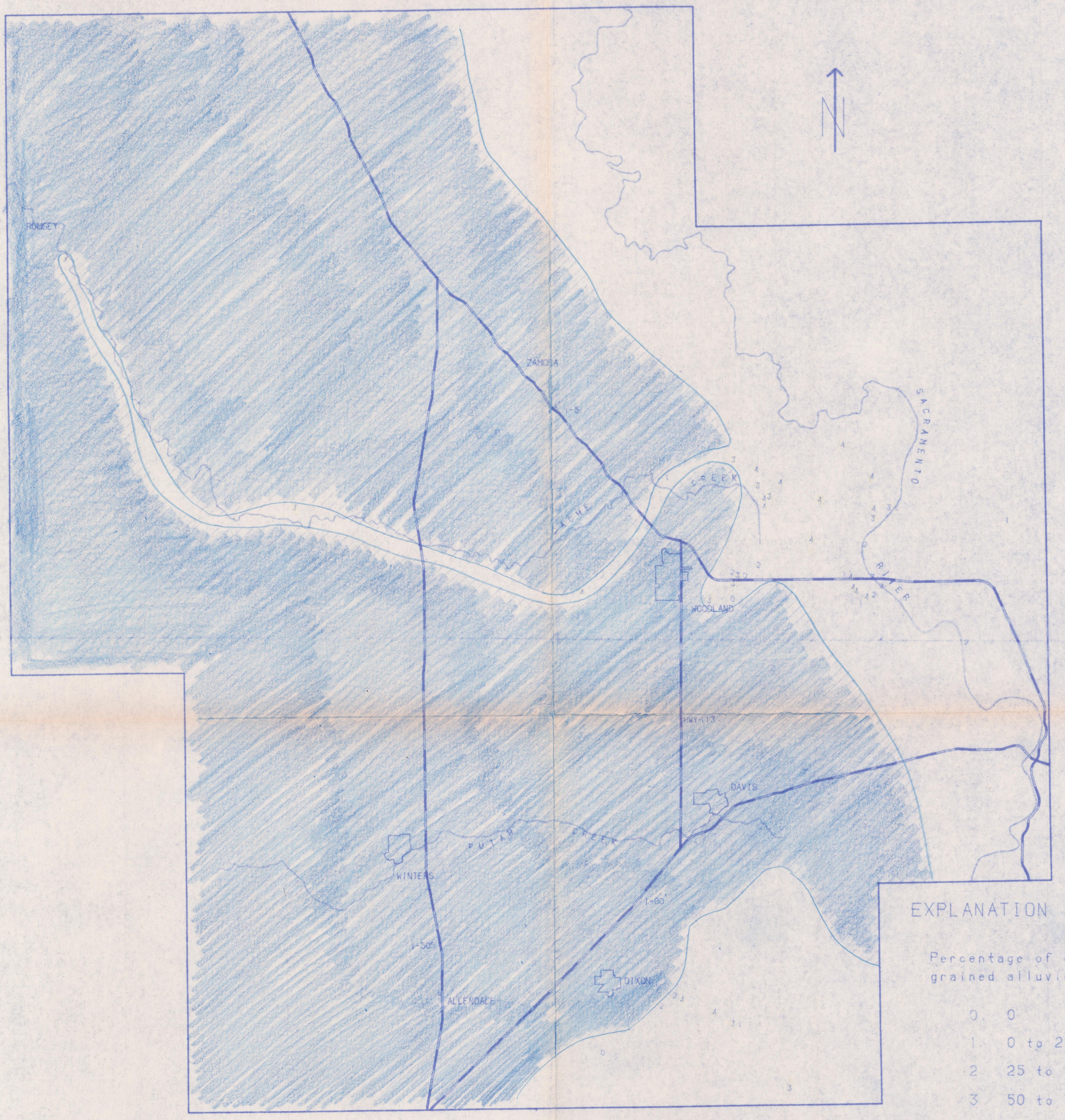
EXPLANATION

Percentage of coarse-grained alluvium:

0	0
1	0 to 25
2	25 to 50
3	50 to 75
4	75 to 100

Tehama Formation and older rocks.

Janice A. Hubbard
Texture Distribution of the Younger Alluvial Sediments and Parts of the Tehama Formation in Portions of Yolo, Solano, Colusa, and Sacramento Counties, California.



EXPLANATION

Percentage of coarse-grained alluvium:

0. 0
1. 0 to 25
2. 25 to 50
3. 50 to 75
4. 75 to 100

Tehama Formation and older rocks.

PLATE 9. Distribution of the percentage of coarse-grained sediments within the 125 to 150 foot depth interval of the younger alluvial sediments.

0 2 4 6 MILES

Janice A. Hubbard
Texture Distribution of the Younger Alluvial Sediments and Parts of the Tehama Formation in Portions of Yolo, Solano, Colusa, and Sacramento Counties, California.

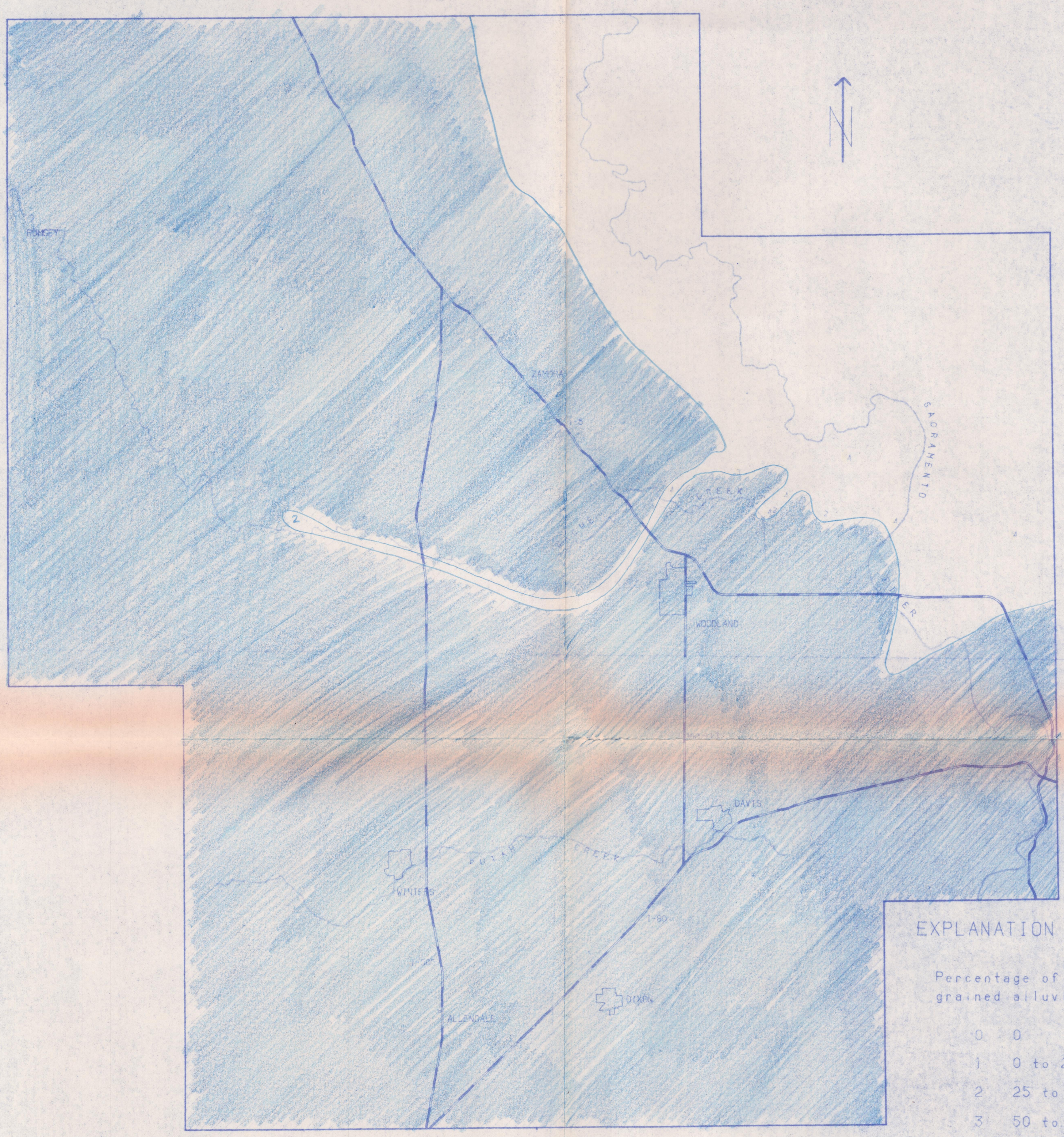


PLATE 10. Distribution of the percentage of coarse-grained sediments within the 150 to 175 foot depth interval of the younger alluvial sediments.

EXPLANATION

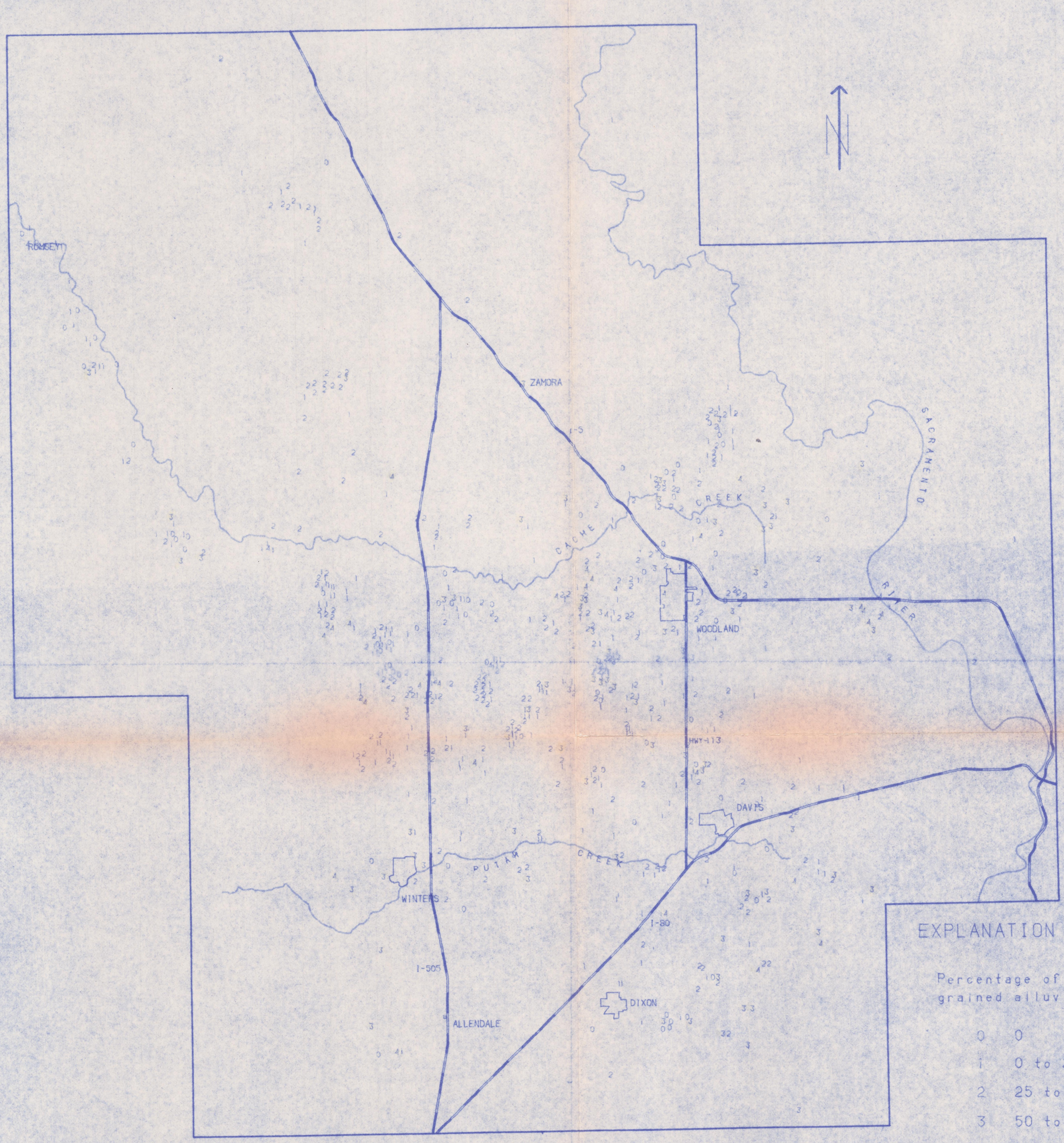
Percentage of coarse-grained alluvium:

0	0
1	0 to 25
2	25 to 50
3	50 to 75
4	75 to 100

Tehama Formation and older rocks

0 2 4 6 MILES

Janice A. Hubbard
Texture Distribution of the Younger Alluvial Sediments and Parts of the Tehama Formation in Portions of Yolo, Solano, Colusa, and Sacramento Counties, California.



EXPLANATION

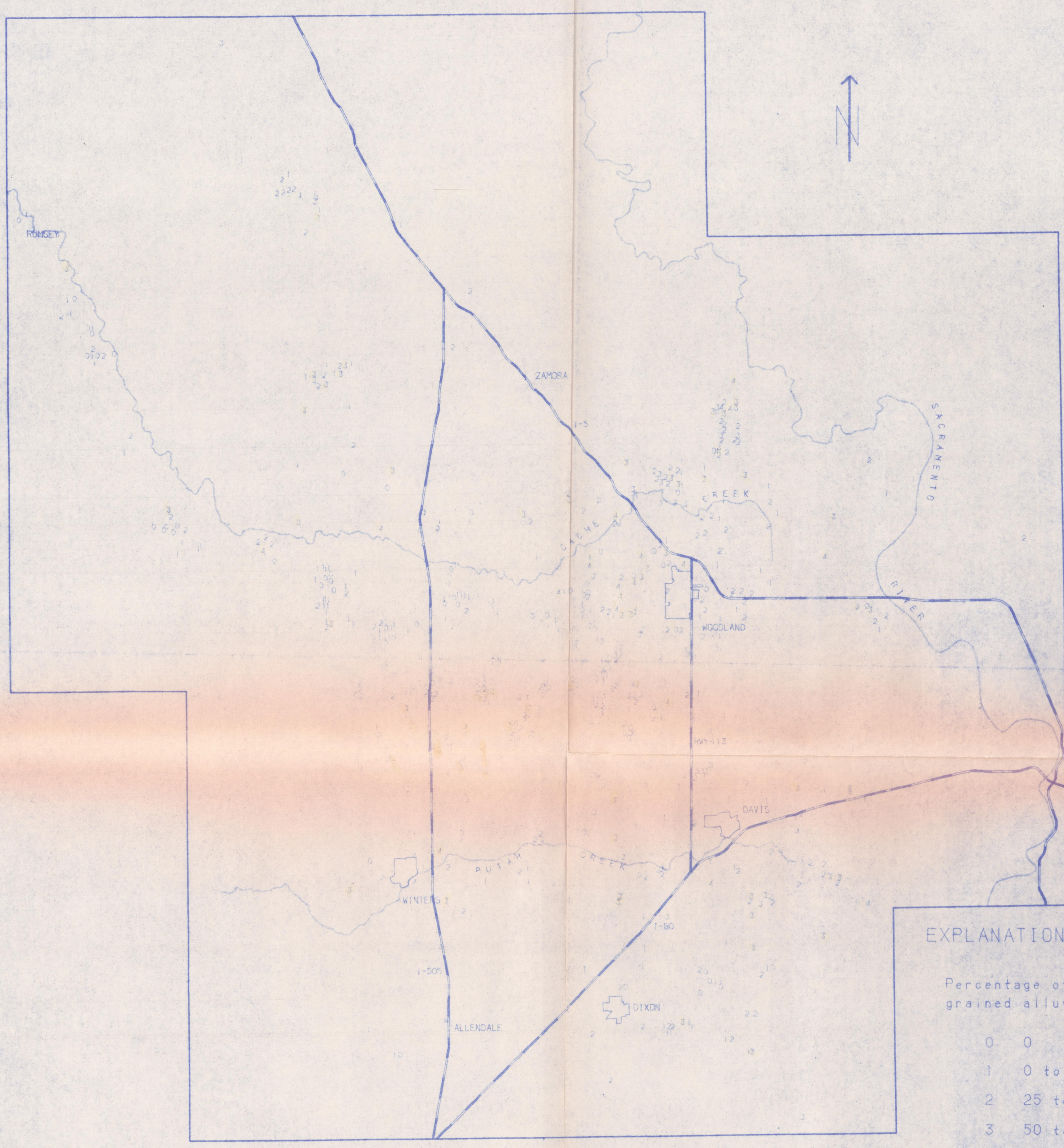
Percentage of coarse-grained alluvium:

0	0
1	0 to 25
2	25 to 50
3	50 to 75
4	75 to 100

PLATE 12. Distribution of the percentage of coarse-grained sediments within the 50 to 100 foot depth interval of the Tehama Formation.

0 2 4 6 MILES

Janice A. Hubbard
Texture Distribution of the Younger Alluvial Sediments and Parts of the Tehama Formation in Portions of Yolo, Solano, Colusa, and Sacramento Counties, California.



EXPLANATION

Percentage of coarse-grained alluvium:

0 0

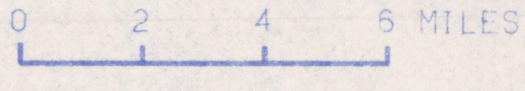
1 0 to 25

2 25 to 50

3 50 to 75

4 75 to 100

PLATE 13. Distribution of the percentage of coarse-grained sediments within the 100 to 150 foot depth interval of the Tehama Formation.



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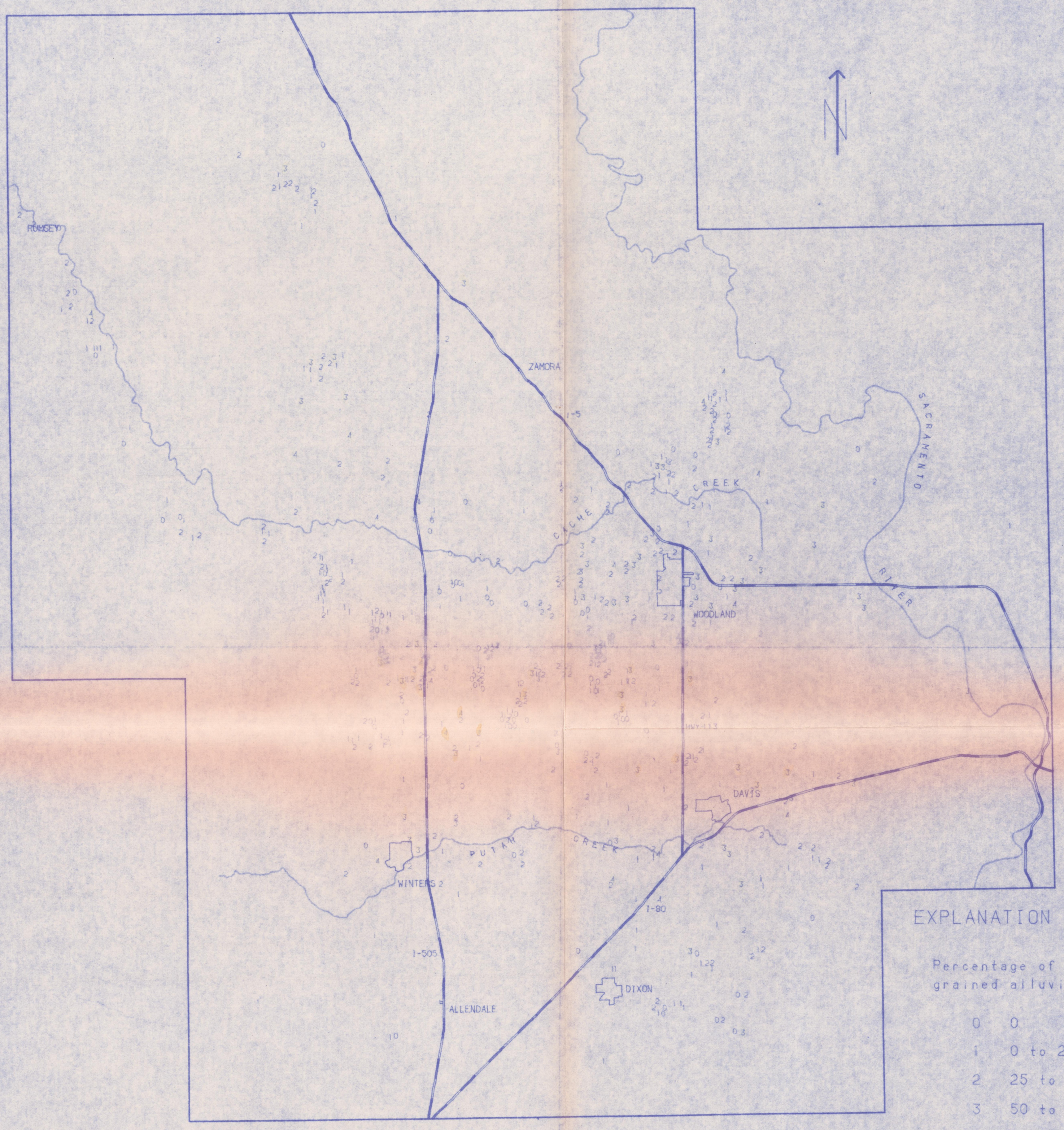
Texture Distribution of the Younger Alluvial Sediments and Parts of the Tehama Formation in Portions of Yolo, Solano, Colusa, and Sacramento Counties, California.



EXPLANATION

Percentage of coarse-grained alluvium:

0	0
1	0 to 25
2	25 to 50
3	50 to 75
4	75 to 100

PLATE 14. Distribution of the percentage of coarse-grained sediments within the 150 to 200 foot depth interval of the Tehama Formation.

0 2 4 6 MILES

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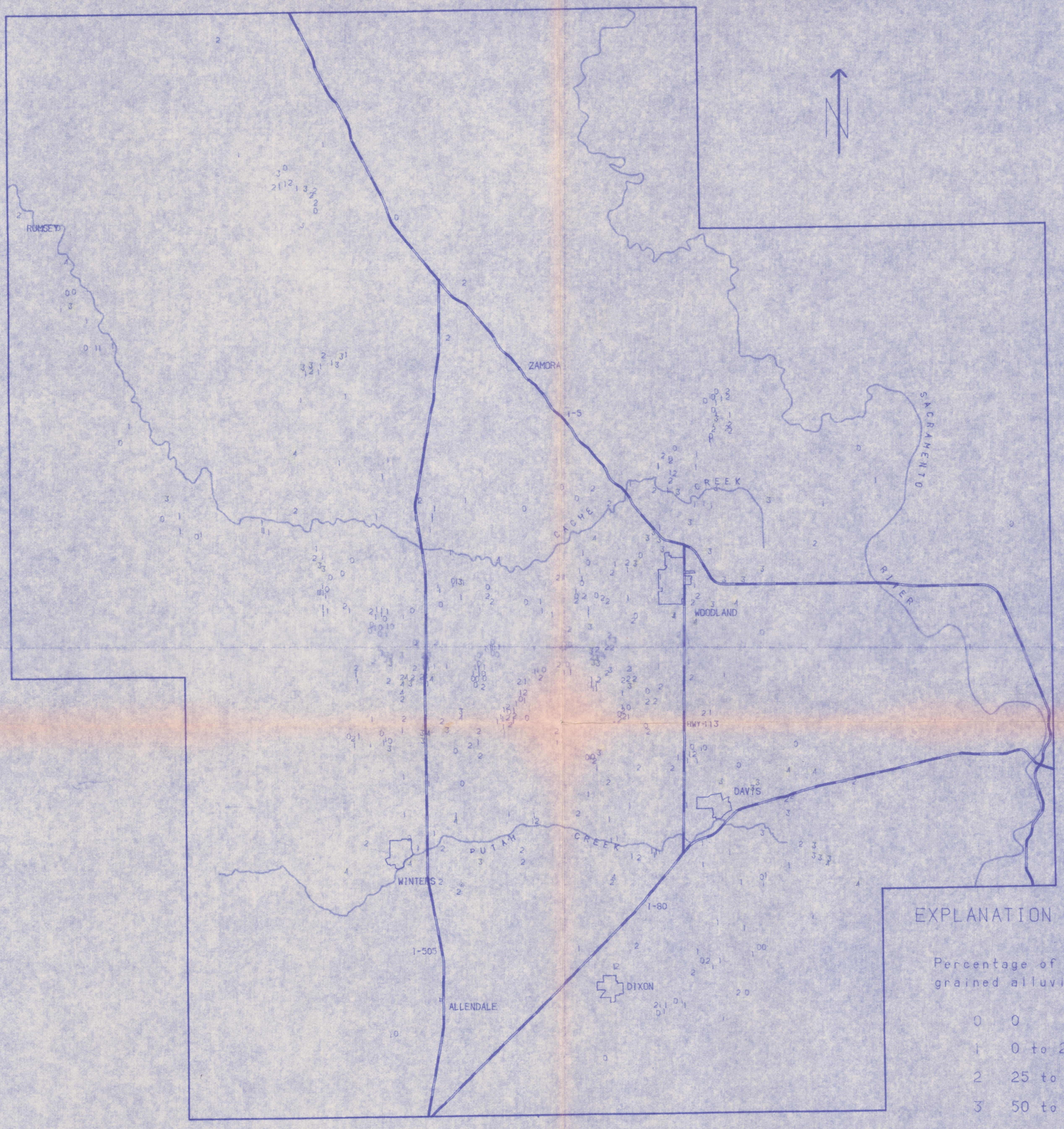
Texture Distribution of the Younger Alluvial Sediments and Parts of the Tehama Formation in Portions of Yolo, Solano, Colusa, and Sacramento Counties, California.



EXPLANATION

Percentage of coarse-grained alluvium:

0	0
1	0 to 25
2	25 to 50
3	50 to 75
4	75 to 100

PLATE 15. Distribution of the percentage of coarse-grained sediments within the 200 to 250 foot depth interval of the Tehama Formation.

0 2 4 6 MILES

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Texture Distribution of the Younger Alluvial Sediments and Parts of the Tehama Formation in Portions of Yolo, Solano, Colusa, and Sacramento Counties, California.

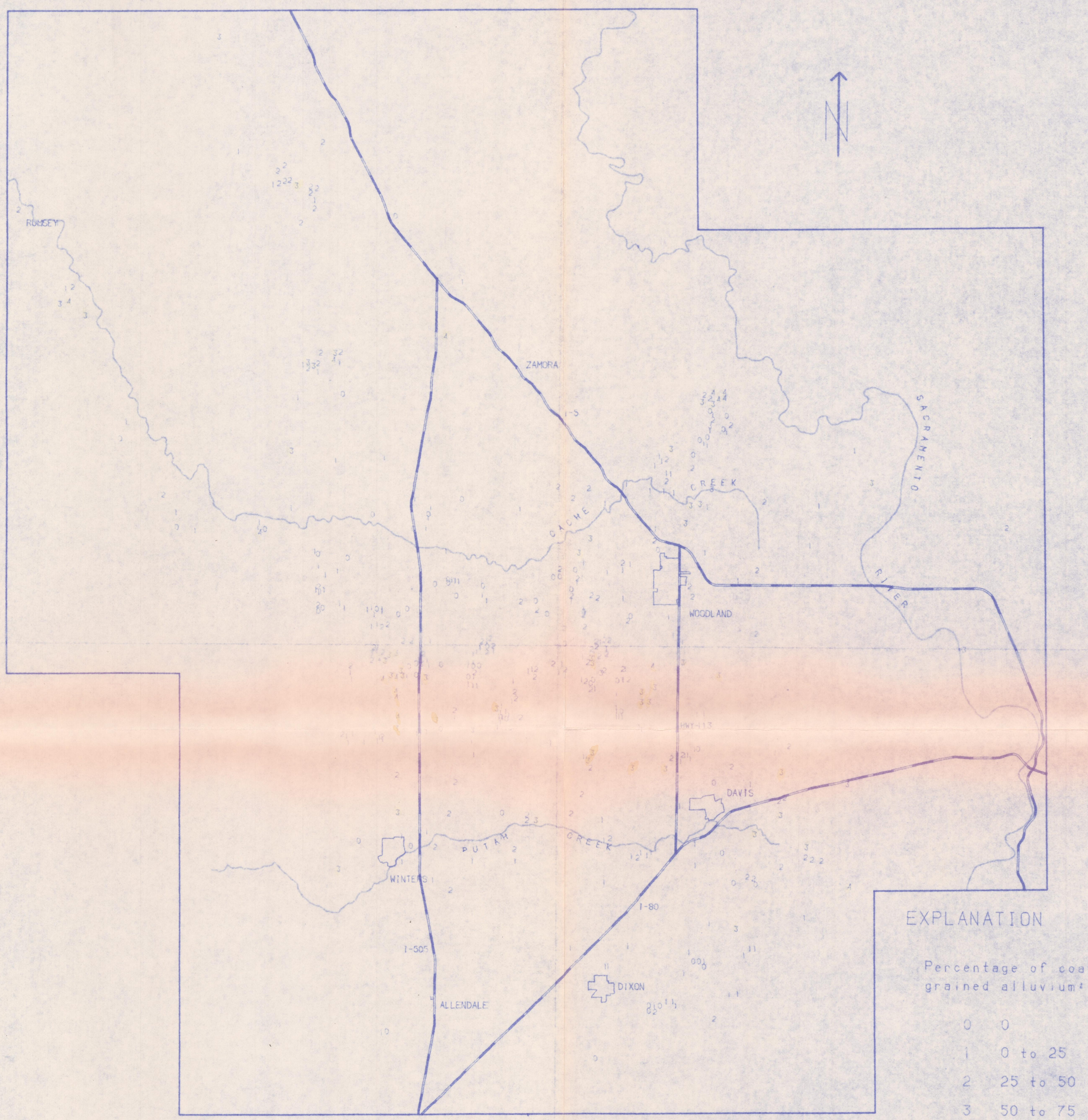

PLATE 16. Distribution of the percentage of coarse-grained sediments within the 250 to 300 foot depth interval of the Tehama Formation.

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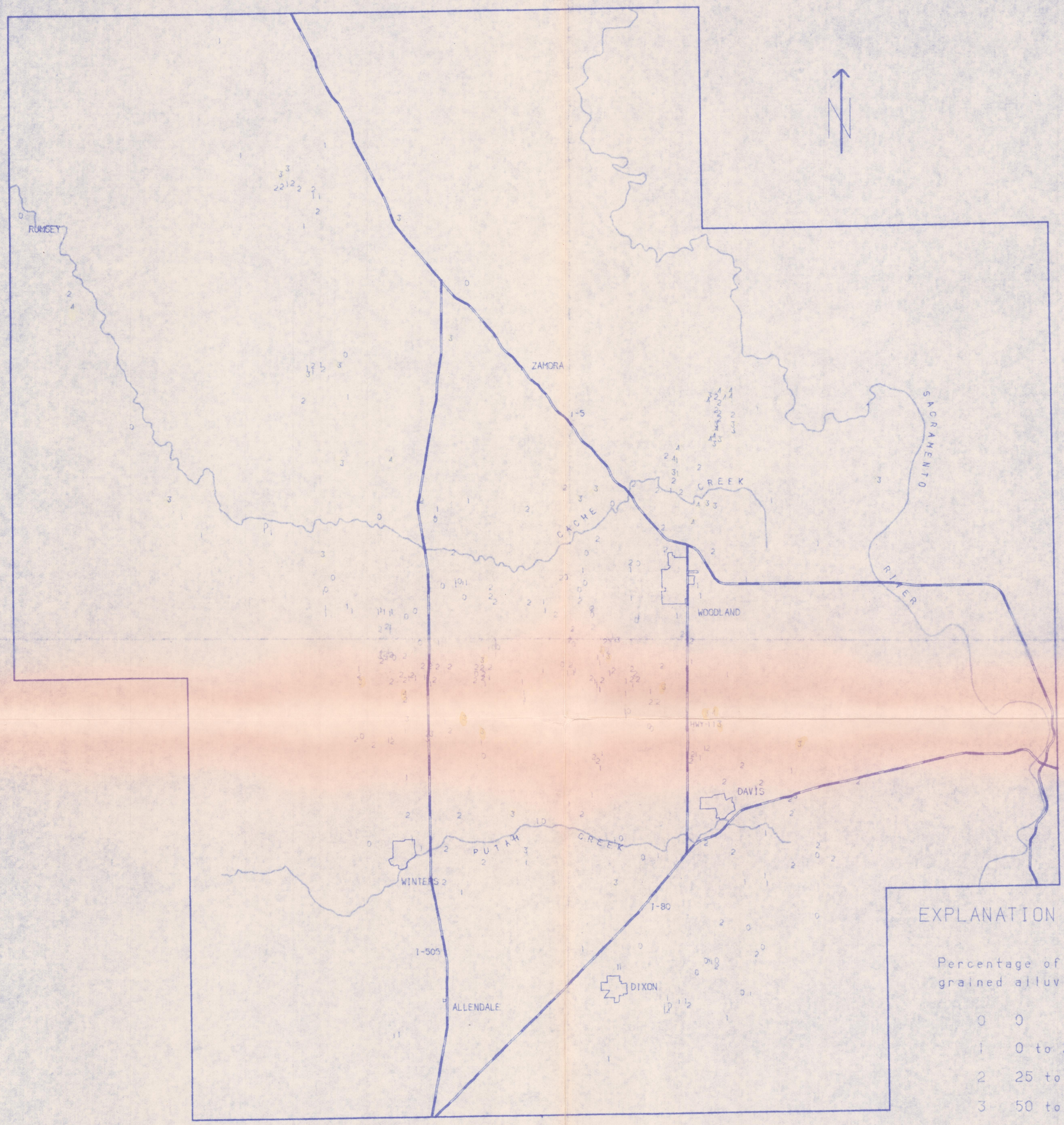
Texture Distribution of the Younger Alluvial Sediments and Parts of the Tehama Formation in Portions of Yolo, Solano, Colusa, and Sacramento Counties, California.



EXPLANATION

Percentage of coarse-grained alluvium:

0	0
1	0 to 25
2	25 to 50
3	50 to 75
4	75 to 100

PLATE 17. Distribution of the percentage of coarse-grained sediments within the 300 to 350 foot depth interval of the Tehama Formation.

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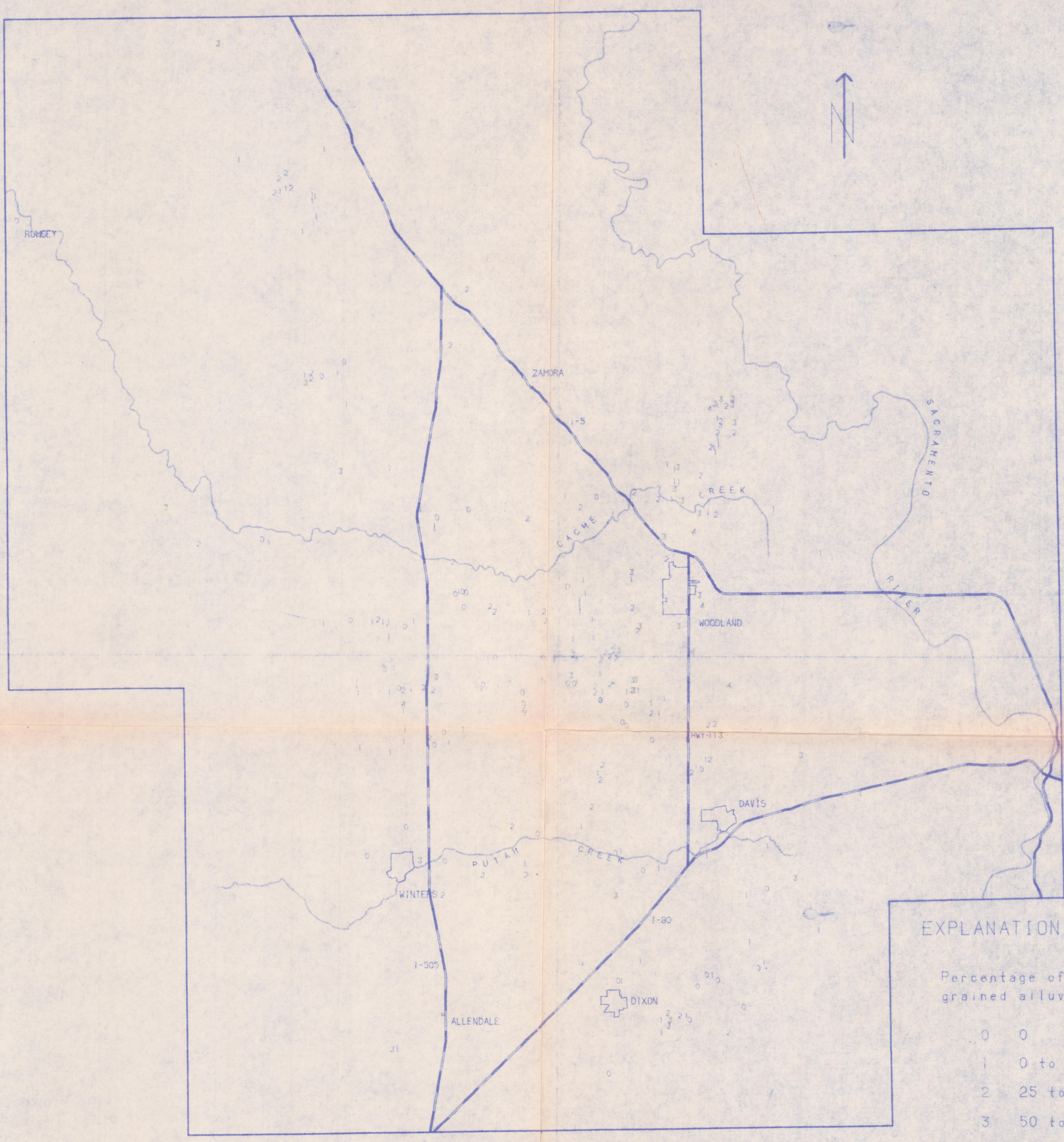
Texture Distribution of the Younger Alluvial Sediments and Parts of the Tehama Formation in Portions of Yolo, Solano, Colusa, and Sacramento Counties, California.



EXPLANATION

Percentage of coarse-grained alluvium:

0	0
1	0 to 25
2	25 to 50
3	50 to 75
4	75 to 100

PLATE 18. Distribution of the percentage of coarse-grained sediments within the 350 to 400 foot depth interval of the Tehama Formation.

0 2 4 6 MILES

Janice A. Hubbard
Texture Distribution of the Younger Alluvial Sediments and Parts of the Tehama Formation in Portions of Yolo, Solano, Colusa, and Sacramento Counties, California.